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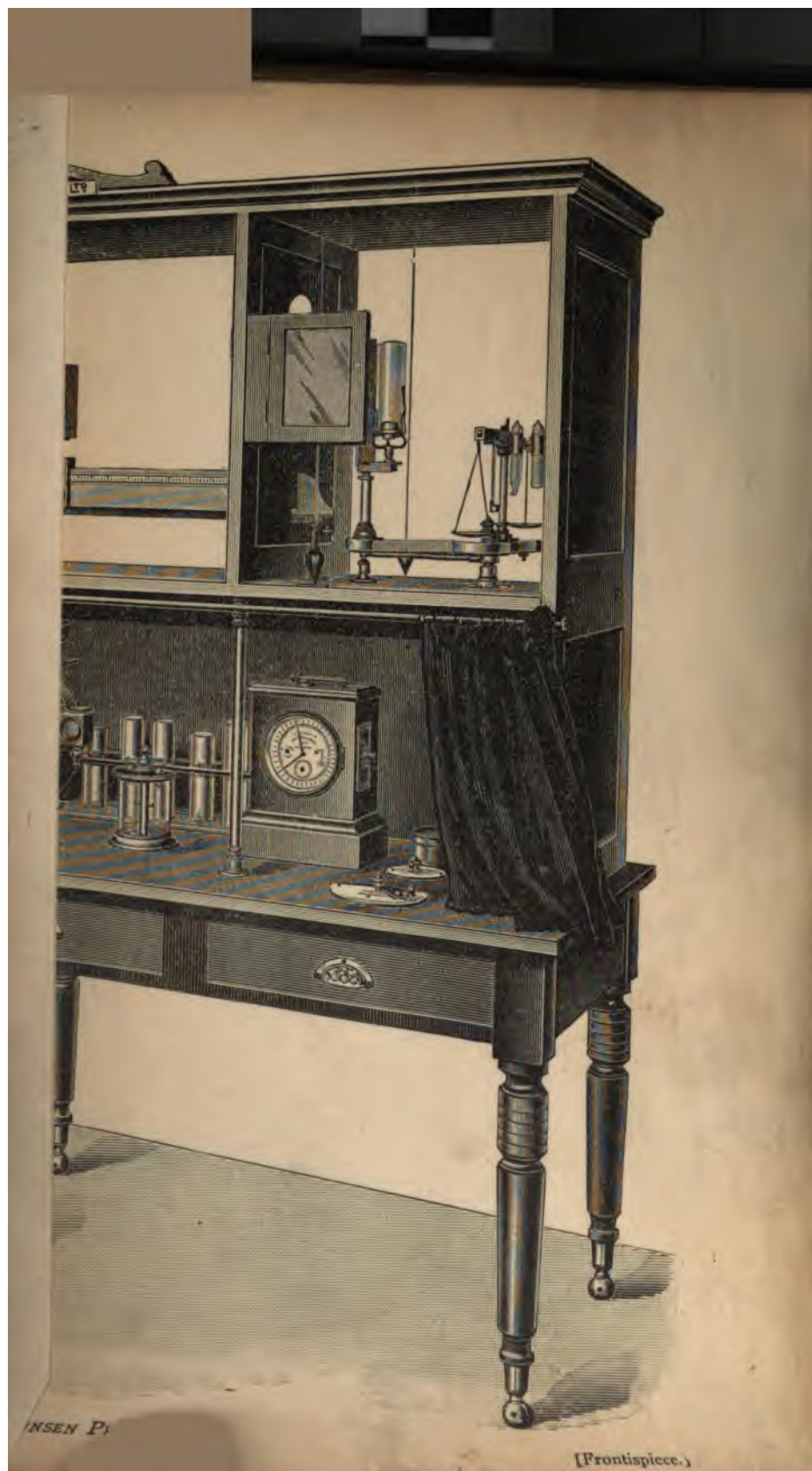


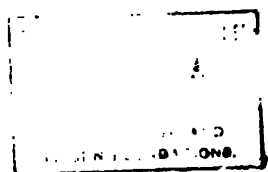


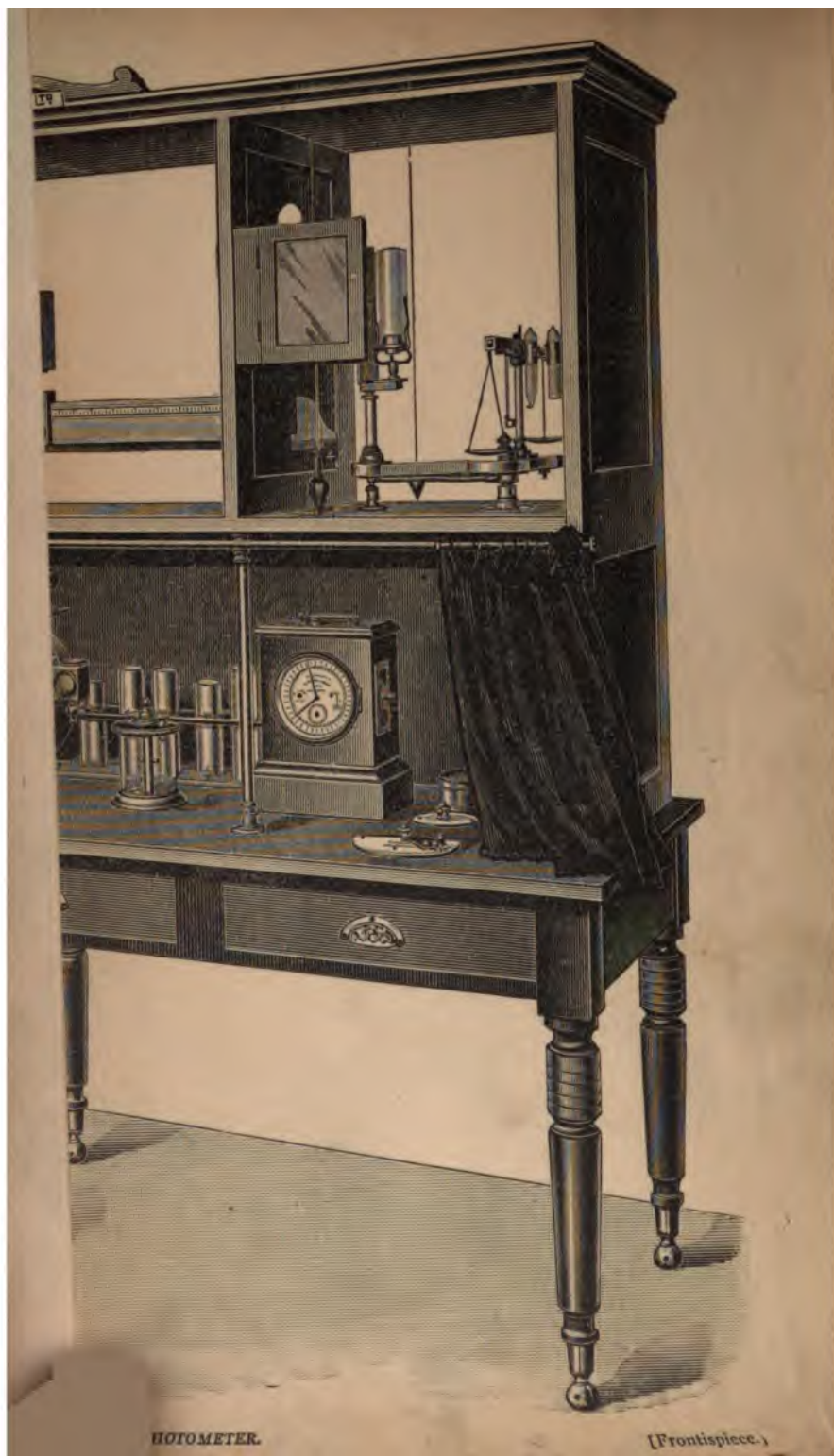
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HYDROMETER.

[Frontispiece.]

GAS ANALYST'S MANUAL

BY

JACQUES ABADY

M. INST. MECH. E.

(INCORPORATING F. W. HARTLEY'S "GAS ANALYST'S
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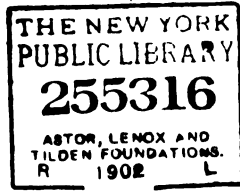
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PREFACE.

numerous requests received by the Publishers for the r. F. W. Hartley's "Gas Analyst's Manual" and Measurement" form the justification of the present which embodies practically the entire contents of those volumes. It has been found, however, that their scope too narrow to comply with modern requirements in various directions, although ample at the time they were written and so I have ventured to add such extensions as are deemed to be necessary in order to meet the demand which exists for a comprehensive work on Gas Apparatus and its use. It was at first proposed to issue the work as a reprint; but when the re-edition was completed, it was found that the greater proportion was new matter; Mr. Hartley's books (except such parts as were superseded by modern practice) being included in Chapters I., XI., and XII., and occasional paragraphs.

It is due to Mr. Hartley's memory to point out that his works have now successfully stood the test of many years, and I can only hope that this volume in its entirety may prove to be of as much service to the gas profession.

Thanks are due, and are freely given, to the various gentlemen who are individually acknowledged in the following pages, and who have rendered great assistance in placing at my disposal tests, figures, records, and friendly criticisms. I specially express my indebtedness to Mr. J. G. Taplay for his invaluable assistance in correcting proofs and other matters which are mentioned in their proper places.

I shall be very glad to receive for use in future editions any criticisms or corrections, which will be gratefully acknowledged.



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CHAPTER I.

PHOTOMETRY.

1. **PHOTOMETRY** is the art whereby the relative illuminating power of lights is determined.

2. Practical Photometry depends, first, on the sensibility of the visual organs and on the mental power to judge, under favourable conditions, respecting the equal illumination of an object; and, secondly, on the law, which is explained fully in text-books on physics, that the intensity of illumination on a given surface is proportional *inversely* to the square of the distance of the surface from the source of light.

3. Many Photometers have been invented, but in England those which are based upon Bunsen's method of ascertaining the relative value of artificial lights have been generally employed. Bunsen invented and employed a screen or disc of paper, greased over part of its surface, so as to render it unequally translucent. The disc was supported or held in an upright position, and the lights to be contrasted were placed one on each side of, but at some distance from, the disc, but in such manner that a straight line, if extended from light to light, would pass through the disc at right angles to its surfaces, and also through each flame midway between its apex and base. The weaker light was then moved toward the disc until the latter became equally illuminated on each side, when, as a consequence, the inequality in the translucency of its parts became invisible or nearly so, owing to the fact that in a position in which

both sides are equally illuminated the quantity of light transmitted through the disc in each direction and the quantity reflected from its surfaces are equal.

4. The distance from the disc to the centre of each light was then measured and squared, and the quotient which resulted from the division of one of the squares by the other gave the relative illuminating power of the flames. Generally the value of the greater light is expressed in terms of the weaker, the latter being regarded as the unit. If, for example, one of the lights were 10 inches and the other 50 inches from the disc, the squares of these numbers are 100 and 2500, and the latter divided by the former would give the value of the greater as 25 times that of the weaker light.

5. Many refinements have been made on Bunsen's method of using the disc, and in the disc itself, for the purpose of rendering the comparison of artificial lights as facile and exact an operation as possible. The most obvious of these consist in the employment of a graduated bar of specific length, the *fixing* of the lights, one at each end of the bar, and the placing of the disc within a box, open at its two ends and in front, which box is provided internally with two reflectors, set at such an angle as to present reflections of the sides of the disc to the observer's eyes, and is carried on a slide which rests upon the bar, and may be freely moved between the lights. The graduations on the bar indicate, on inspection, the value of the stronger light in multiples of the weaker, thereby saving trouble, and preventing the possibility of errors which might, in the absence of such graduations, arise from inaccuracy in measurements and in calculations.

6. The fixing of the lights conduces to regularity of combustion and to steadiness of the flames, which are likely to be prejudiced by motion. Other, and possibly not less

important, refinements have been introduced; the value of these may be understood from what follows.

7. A reference to par. 3 will show the extent to which Bunsen's system has been adopted in England. The exception is an important one, for the town in which primarily another system is used is London itself. The importance of this is increased, first, by the fact that London is unique in having a specially constituted body of competent experts—the Metropolitan Gas Referees—to regulate the testing of gas; and, secondly, by the fact that several important towns have followed London's lead, and are substituting the new method for Bunsen's.

8. It will be sufficient to state here (the subject being dealt with fully in the body of the book) that in the new method the Bunsen disc is abandoned, and the lights are instead placed at equal angles to a slotted plate, in which is placed a piece of white paper of fine grain, unglazed, and free from water-marks. Before this paper is placed a tube, carrying a plate with a comparatively narrow slot, and the positions of the lights to be compared and paper are such that two illuminated bands are thrown on its surface, which are equal in intensity when the lights are equal. The principle is, of course, an old one, and the adoption of the method is due to Mr. Vernon Harcourt.

The Purposes of Photometry.

9. Photometry is practised for several purposes—namely, to ascertain the relative value of various substances used in artificial illumination, and the most advantageous methods of burning them; as a means of selecting burners which are suited for evolving the greatest effect from any illuminating gas, and as an aid to the improvement of burners themselves, etc.—but the purpose for which Photometry is most extensively practised is to discover whether the coal-

gas supplied by gas companies is of such quality, in respect to illuminating power when burned under fixed conditions, as the companies are bound, either by special or general acts of Parliament, to furnish. It is to the last-mentioned application that the reader's attention will be particularly directed in the following pages.

Standard Light.

10. "The light adopted in the United Kingdom, except London, under the authority of the legislature, and also in the colonies, as a standard whereby to estimate and express the illuminating value of coal-gas, is that which is derived from a sperm candle burning at the rate of two grains of sperm per minute, or, as usually specified, sperm candles of six to the pound, each burning 120 grains an hour. Few candles burn at this exact rate, and in practice, if the rate of consumption per candle shall not have exceeded 126 grains per hour, or fallen short of 114 grains per hour, corrections by calculation are made for such variations from the standard rate. The candle standard is by no means a perfect one, but, in spite of its defects, it has many advocates. It certainly is a most convenient standard by which to express the value of gas, and when due care is exercised, and a sufficient number of experiments made on each occasion, the operator may arrive at results sufficiently accurate for all practical purposes."

11. Although Mr. Hartley's foregoing remarks represented, at the time they were written, the general opinion, attention was already being drawn to a standard of light which would be more certain and accurate and require less care in manipulation than the standard candle. These efforts have continued to the present day, and are epitomised in the section "Standards of Light," and the fact that a Pentane standard has been prescribed and adopted in

London will undoubtedly influence the future of Photometry so far as the United Kingdom is concerned. There is no doubt that the results claimed by Mr. Hartley for the candles can be obtained without trouble by several of the standards, notably, either by Harcourt's 10-candle Pentane lamp, Simmance's Pentane burner, or under certain circumstances by Methven's screen.

Standard Burner.

12. Anterior to about the year 1860, the descriptions which were inserted in acts of Parliament of the burners to be used in testing were most unsatisfactory, it being deemed sufficient to specify that the burner employed for common gas should be "an Argand burner, having 15 holes and a 7-inch chimney." As a consequence, burners differing widely in their dimensions, in the proportion of their parts, and in their capability to develop the light power of the gas were employed. The necessity for defining the burner was at last recognised, and attempts were made to do so, but not always with success, as witness the following description of a 15-hole Argand, extracted from the "Birmingham and Staffordshire Gas Act, 1864":

A metal Argand burner having an external diameter of 1.10 inch, and an internal diameter of 0.50 of an inch, and having fifteen holes, each hole of the diameter of 0.05 of an inch, and with a 7-inch chimney supported upon an ordinary gallery without perforated disc.

13. The above-mentioned burner proved to be a very indifferent one, and the description is defective in several particulars, which, however, it is needless to discuss, as the 15-hole burners now generally employed are either of the Sugg-Letheby model or the 15-hole London burner, the latter being similar, except as to the number of its holes, to the "Standard burner, deposited with the Warden of the

Standards [Board of Trade], in accordance with Section 37 of the Gaslight and Coke Company's Act, 1876." The burner which was designed, and formerly made solely by Mr. Sugg, is known officially as "Sugg's London Argand No. 1," but is variously styled "Standard London Argand burner" and "24-Hole Argand burner." It was formerly made principally from cast white metal in a mould, but in about the year 1892 Mr. Frank Wright made it of cast brass and so con-

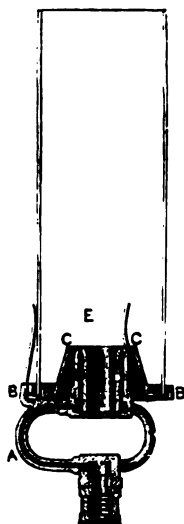


FIG. 1.—STANDARD ARGAND BURNER.

structed it that all the internal parts could be accurately machined and smoothly finished. The advantage of this method of construction is that the friction is slightly reduced, with a corresponding reduction of the pressure at point of ignition, thus slightly improving the illuminating power under certain conditions.

A section is appended, in which A represents a supply pipe, B the gallery, C the cone, D the steatite chamber, E the chimney. (Fig. 1.)

The following are the dimensions of those parts of the burner upon which its action depends:

	Inch.
Diameter of supply pipes.....	0.08
External diameter of annular steatite chamber..	0.84
Internal diameter of do.....	0.48
Number of holes.....	24.
Diameter of each hole.....	0.045
Internal diameter of cone:	
At the bottom.....	1.5
At the top.....	1.08
Height of upper surface of cone and of steatite chamber above floor of gallery.....	0.75
Height of glass chimney.....	6
Internal diameter of chimney.....	1 $\frac{3}{4}$
The standard burner for testing cannel gas is a steatite batswing burner, consisting of a cylindrical stem, the top of which is divided by a slit of uniform width.	
	Inch.
External diameter of top of stem.....	0.31
Internal diameter of stem.....	0.17
Width of slit.....	0.02
Depth of slit.....	0.15

The makers provide each burner with a second chimney, which is also 6 inches in height, but 1 $\frac{3}{4}$ inches only internal diameter. The smaller chimney is required with gas below 16 candles illuminating power.

14. Many gas companies are still in an unfortunate position under the clauses of their acts of Parliament and of those of the Gas Works Clauses Act Amendment Act, 1871, the Schedule A of which recites that "the burner to be used for testing shall be such as shall be prescribed." In justice to such companies the "prescribed" burner ought in every instance to be the same as that used in London, so that the true relative value of the gas they supply to that supplied in the metropolis could be known, and thereby the publication of any statements as to apparent inferiority in quality, which may be due to the burner and not to the gas,

be avoided. Pending the possible further amendment of the Gasworks Clauses Act, companies, especially those which are prejudicially affected, would do well to urge upon their consumers the employment of good burners, and thereby smooth the way in the proper direction.

15. GAS WORKS CLAUSES ACT AMENDMENT ACT, 1871.

SCHEDULE A.

PART I.

Regulations in respect of testing apparatus.

(1) *The apparatus for testing the illuminating power of the gas* shall consist of the improved form of Bunsen's Photometer, known as Letheby's open 60-inch Photometer, or Evans's enclosed 100-inch Photometer, together with a proper meter, minute clock, governor, pressure gauge, and balance.

The burner to be used for testing the gas shall be such as shall be prescribed.

The candles used for testing the gas shall be sperm candles of six to the pound, and two candles shall be used together.

(2) *The apparatus:*

(a) *For testing the presence in the gas of sulphuretted hydrogen.*—A glass vessel containing a strip of bibulous paper moistened with a solution of acetate of lead, containing sixty grains of crystallized acetate of lead dissolved in one fluid ounce of water.

PART II.

Rules as to mode of testing gas.

(I.)—*Mode of testing for illuminating power.*

The gas in the Photometer is to be lighted at least fifteen minutes before the testings begin, and it is to be kept continuously burning from the beginning to the end of the tests.

Each testing shall include ten observations of the Photometer made at intervals of a minute.

The consumption of the gas is to be carefully adjusted to five cubic feet per hour.

The candles are to be lighted at least ten minutes before beginning each testing, so as to arrive at their normal rate of burning, which is shown when the wick is slightly bent and the tip glowing. The standard rate of consumption for the candles shall be 120 grains each per hour. Before and after making each set of ten observations of the Photometer, the gas examiner shall weigh the candles, and if the combustion shall have been more or less per candle than 120 grains per hour, he shall make and record the calculations necessary to neutralise the effects of this difference.

The average of each set of ten observations is to be taken as representing the illuminating power of that testing.

(II.)—*Mode of testing.*

- (a) *For sulphuretted hydrogen.*—The gas shall be passed through the glass vessel containing the strip of bibulous paper moistened with the solution of acetate of lead for a period of three minutes, or such longer period as may be prescribed; and if any discoloration of the test paper is found to have taken place, this is to be held conclusive as to the presence of sulphuretted hydrogen in the gas.

16. The foregoing are the regulations and rules which practically apply to the whole of the Kingdom, inclusive of London (subject to the modifications referred to); but the Referees direct that corrections shall be made for barometric pressure and temperature, and this ought certainly to be done in all cases. The method of making such correction will be explained in the proper place.

17. The propriety of so correcting the indicated illuminating power of the gas will be realised when it is remembered that gases (and vapors) are in this country assumed to be of *normal bulk*, and therefore to possess their *normal density*, when under an atmospheric pressure of 30 inches

barometer and at a temperature of 60° Fahr. It is true that in scientific investigations it is now generally assumed that gases are of standard volume under a pressure of 760 millimetres (29.92 inches), and at the temperature of 15° Centigrade (59° Fahr.), but at 30 inches and 60° Fahr. gases are at their average density in this country, and therefore corrections of volume to that pressure and temperature are justly made in gas testing, which is really a determination of its commercial value.

18. Now, under an atmospheric pressure *below* 30 inches or at a temperature *above* 60° Fahr. any gas or vapour is *below* its normal density, and in the case of illuminating gas any measured volume contains *less* than the normal weight of illuminating matter. With a pressure *above* 30 inches or temperature *below* 60° Fahr. the reverse effect results, and any measured volume would contain *more* than the normal weight of illuminating matter. Sometimes it happens, although rarely, that a rise or fall in pressure may be accompanied by such a rise or fall in temperature that the standard density is maintained; thus, at 30.8 inches and 70° this is the case, as it is also at 29.7 inches and 56°, as will be seen from the Tabular Numbers in Appendix. The numbers in that table have been calculated from the formula

$$n = \frac{17.64(h - a)}{460 + t} \text{ where}$$

h is the height of the barometer in inches, t the temperature on the Fahrenheit scale, and a the tension of aqueous vapour at t° . If v is any volume at t° , and h inches pressure, and V the corresponding volume at 60° and 30 inches pressure, then $V = v_n$.

19. In order to arrive at the tabular number, three processes are necessary—namely, an observation of the barometer, a reading of the thermometer attached to the

meter, and a consultation of the tables which give the tabular number. A labour-saving device, the Aerorthometer, has been introduced, and is used with the new Standard Photometer for London, by means of which at one observation a number is obtained—the Aerorthometer number.

This number is $\frac{1}{n}$ where the tabular number is n , so that

where the tabular number is used as a divisor the Aerorthometer number is used as a multiplier, or *vice versa*. There is, however, no particular advantage, other than that of saving time, in the use of this with ordinary Photometers; indeed, the instrument cannot be said to be as reliable as the thermometer and barometer are, principally because of its sensitiveness and of the doubt whether requisite care to prevent its being affected by radiant heat will be taken by the experimentalist. It is, however, a useful instrument, and its use is advantageous with the new Standard Photometer for London, as will be shown hereafter.

20. The importance of the correction herein mentioned is best realised by an extreme illustration. Suppose, then, that gas were adjusted to burn at the 5-cubic-feet rate when the barometer was at 28 inches and the temperature 84° ; the table shows that the measured volume is only the 870-1000ths of the normal volume, or 4.35, instead of 5 cubic feet.

Description of Standard Apparatus.

21. The apparatus which will be herein described, as conforming with the requirements of the Gas Works Clauses Act (par. 15), consists of the instruments named below:

The Letheby-Bunsen Photometer,
The Candle Balance,

The Experimental Meter,
The Minute-Clock,
The Experimental Governor,
The Pressure Gauge,
The Burner,
The Sperm Candles,
The Bunsen Disc.
The Glass Vessel or Sulphuretted Hydrogen Test,

all of which are absolutely essential; but to render the apparatus complete the following are also required:

A Governor for the Service Pipe,
A good Barometer,
A Standard Measure for Testing the Meter.

22. It will be observed that Mr. Hartley only mentions the Letheby-Bunsen Photometer, although the Gas Works Clauses Act mentions Letheby's open 60-inch Photometer or Evans enclosed 100-inch Photometer. Now, it is no part of the design of this book to enter upon any debateable questions, but it may be noted that Mr. Hartley in thus pointedly ignoring the Evans Photometer seems to have been gifted with a prophetic vision of what would be the verdict of a generation later. The question of an open Letheby or a closed Evans Photometer has until recently been a hotly debated one, and it will be conceded that the spoils of the fight have fallen to the advocates of the open system. The form of the Evans has been altered in several important respects—the size of the box, the ventilation of the box, the fixed disc box, the movable candles, for instance, in order to get rid of defects which have proved to be inherent to the system of closed Photometers. On the other hand, the essential points in the Letheby Photometer are unchanged, and Mr. Hartley's description practically stands good at the present day. That the instru-

ments and their arrangement have been modified is only the outcome of the natural progress which time brings in its train, but the essential points are identical with those at the time when the act was passed which is in force at the present day, and is known as "(33 & 35 Vict.) Gas Works Clauses Act (1847), Amendment Act (ch. 41), A.D. 1871."

23. *The Letheby Photometer* is shown in the frontispiece. Photometers to this model are verified and stamped by the Standards Department of the Board of Trade. The graduated bar is of such length that the centres of the flames to be contrasted shall be 60 inches apart, the positions of the flames being fixed (par. 5). The bar is of polished wood, and is graduated each way from its centre into spaces, numbered 1, 2, 3, and upward, to the ends of the two scales thus produced. The centre line, numbered 1, or unity, indicates the position at which the disc (par. 3) would be equally illuminated on both of its sides if the contrasted lights at the ends of the bar were of equal power, and 2, 3, etc., the positions for the disc, if the stronger light were two, three, or four times greater in light-giving power than the weaker (par. 4).

24. The numbered divisions (units) up to the second are divided into hundredths, so that a close reading can be made with a 10-candle standard; those up to the ninth are subdivided into tenths, thence into halves up to 20, and from that point completed by entire units of indicative value.

25. The saddle, or slide, is provided with brass rollers, in order that it may travel easily and smoothly on the bar, and is furnished with a prismatic refractor, to throw the light upon the pointer, which is mounted on the saddle centrally with the disc box. The disc box is fitted internally with a disc holder and with two mirrors (par. 5). The disc holder is reversible, so as to equalise any error in the observation, and enable each half of the tests to be made

with a different side of the disc presented to the same source of light. The gas pillar communicates with the service, the regulating cock, and with the pressure communicator, by means of which the pressure at the point of ignition is ascertained. At each end are upright, black wooden screens, and there are similar screens with central holes,

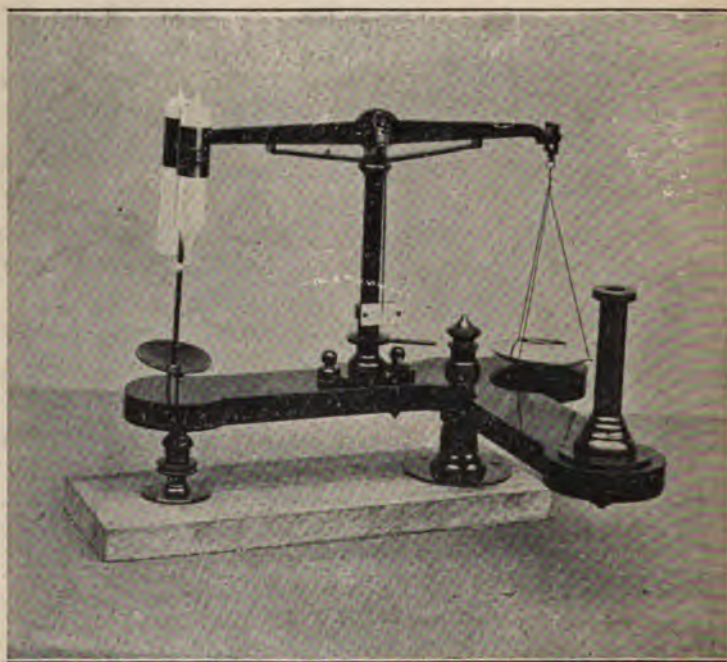


FIG. 2.—TRI-ARM FOR USE WITH CANDLES AND ANOTHER STANDARD.

through which the rays of light pass from the flames to the disc. Upon the baseboard the bar, etc., are fixed.

26. *The Candle Balance.*—This is a very sensitive and accurate instrument, capable, if properly used, of weighing to the fiftieth of a grain. The end of the beam nearest to the disc box carries a holder for two candles, so

that the candles may be weighed while in position for use and while actually burning. The operator is thus enabled to burn the candles under conditions most favourable to regularity of combustion, and also to weigh them with great exactness.

27. In some Photometers (and in the one that is illustrated here) there is provided an arrangement (see Fig. 2) called the tri-arm. This is a platform, revolving on a pillar, through which when the arm is in one direction there passes a coal or Pentane gas supply to a pillar with ground socket for the reception of a Methven screen or other convenient standard. A quarter of a turn of the arm brings the candle balance into position and at the same time shuts off the gas. Thus, tests can be made with alternate standards without waste of time or readjustment of the Photometer centres.

28. *The Experimental Meter.*—The dial of this meter has three divided circles and three pointers. Two of the circles are concentric, while the third is a small secondary one. A long pointer indicates on the outer circle, a shorter one on the inner, and another pointer from a separate centre on the secondary circle. (Fig. 3.)

29. A complete revolution of the long pointer indicates the passage and measurement of $\frac{1}{12}$ th of a cubic foot of gas, or the quantity which must be burned in one minute to secure the standard rate of five cubic feet per hour. The outer circle is divided into five principal divisions, and as each of these represents $\frac{1}{5}$ th of $\frac{1}{12}$ th of a cubic foot, or $\frac{1}{60}$ th of a cubic foot, it follows that the quantity of gas indicated by the passage of the pointer from one of these five divisions to the next bears the same ratio to a cubic foot of gas as one minute does to an hour. The subdivisions bear the same ratio to tenths of a cubic foot.

30. The secondary small circle is divided into 12 equal parts, and the pointer makes a complete revolution while

the long pointer referred to above goes round 12 times—in fact, the complete revolution of this small pointer indicates the passage of 1 cubic foot of gas.

31. Disregarding the secondary pointer a minute, if the long pointer were started at zero, and at the end of a minute were half way between 4 and 5, it would be travelling and



FIG. 3.—EXPERIMENTAL PHOTOMETER METER.

the gas passing at the rate of 4.5 cubic feet per hour—that is to say, would actually have passed in one minute $\frac{4\frac{1}{2}}{60}$ ths.

32. In taking an extended test, say over 10 minutes, the secondary pointer is brought into use. Thus, if the meter were started with both pointers at zero, and at the end of

10 minutes the secondary one were at 9 and the long one midway between 4 and 5, then

$$\frac{9}{12} \times 6 = 4.5$$

$$\frac{4\frac{1}{2}}{60} \times 6 = .45$$

4.95 feet per hour.

It will be seen that if the gas is passing at 5 feet per hour, the long pointer will be at zero and the secondary pointer at $\frac{1}{2}$ ths at the end of 10 minutes.

33. The small central pointer, indicating actual feet on the concentric inner circle, is not used in Photometry, but for other purposes to which an experimental meter may be applied. It will be apparent, however, that if the meter is being used with the long pointer indicating actual consumption (as opposed to calculated consumption from one minute's observation), a reading can be taken to $\frac{1}{80}$ th of a cubic foot, each division on the outer circle bearing this value. Finally the hands can be set to zero, and a bell rings at every revolution of the long pointer, so that adjustment can be made orally, the rate being adjusted till the meter bell rings coincidentally with the clock bell, which is of a different tone.

34. Another form of experimental meter is sometimes used, and is known as a clock-meter. This is arranged with a minute hand of a clock and the hourly rate hand of the meter moving from the same centre, so that if they travel at the same rate, the meter is passing 5 feet per hour. There are some objections to this—firstly, that if the clock has to be removed for repairs, the meter is placed *hors de combat*; and, secondly, the short pointer of the meter, which is geared indirectly from the drum, conceals irregularities in the working of the drum, which it is most important the

experimentalist should be aware of, but which are instantly exposed by the more sensitive long central pointer, which is sleeved directly on the spindle of the drum. Another objection is that the clock does not set to zero, so it is not convenient to use it for timing the candles, and therefore another clock is necessary.

35. It should be clearly stated that the so-called dry experimental meters are absolutely useless for experimental purposes, and the only form recognised by the Standards Department and the Gas Referees is the wet meter. The construction of these wet meters has been greatly improved, and in order to avoid the frequent case repairs necessary with tin meters, the cases of the ordinary experimental meter are made of incorrodible porcelain, as well as all the other parts of the apparatus which are liable to perish.

36. The meter must stand perfectly level, and be charged with water until the lower part of the meniscus, or cup, formed by the water within the gauge at the side of the meter (Fig. 3), coincides with the line marked on the glass front. Or, if the meter be provided with a drip socket on its side, instead of a water-line box, it must be allowed to rest until the excess water is completely drained off. The socket is to be closed by inserting the screw plug. This, of course, must be done when the gas is off and the meter open to the atmosphere. The small hand may be freely moved backward, and the pointers thereby set at zero when desired.

37. *Testing the Meter.*—The question of the water-line of the meter is an important one, and however carefully it is adjusted and marked before being sent out, what might be termed the personal error in observing the water-line after filling is quite sufficient to make an appreciable difference in the correctness of the meter. Strictly speaking, the experimental meter ought to be tested with a cubic-foot bottle once a week; and this, no doubt, would be done, but the acquisi-

tion of a cubic-foot bottle is a rather expensive luxury, while its manipulation occupies too long for a busy experimentalist, and leads to the neglect of this important point. Another objection is that the passing of air for such an extended period renders a long subsequent passage of gas necessary before correct photometrical results can be obtained. The $\frac{1}{2}$ th cubic-foot bottle, as introduced and made compulsory in the London Testing Stations, affords a convenient method of correcting the water-line of the meter, and can be used with the gas in the Photometer service without unfixing the meter or any of the apparatus or admitting any air. A description of the apparatus will be found in par. 138. It can be used in the manner described therein by the provision of the three-way cock to the gas supply at the inlet of the meter, and is a very useful addition to a Photometer. (See Fig. 22.)

38. *The Minute Clock.*—The most convenient form of clock is that represented in Fig. 4. The circumference of



FIG. 4.—STANDARD MINUTE CLOCK.

the dial is divided into seconds, and also into 100 divisions, so that part of a minute may be read off to the second

decimal place. It is furnished with a stopping and starting lever at the side, and with a press button at the top, by which the hands may be instantly set at zero—that is, upright. The small dial indicates 10 minutes, which is the time occupied in each set of photometric observations. Finally, each completed revolution of the long pointer, and therefore the passage of one minute, is notified by the strik-

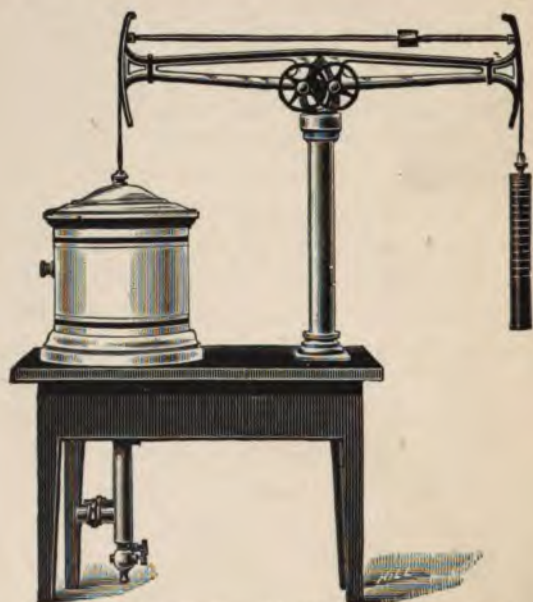


FIG. 4a.—EXPERIMENTAL BALANCE GOVERNOR.

ing of a bell within the clock case. Since Mr. Hartley's day an improvement has been made to this form of minute clock in the shape of a sperm consumption circle on the dial, and by means of which the calculation for correction of sperm consumption is obviated. This circle is printed in red, so as to be easily distinguished from the clock indications. As an example, suppose when the candle balance turns, and the clock is stopped, it reads 9 minutes 57 sec-

onds. The pointer which indicates the seconds will also be found to point to 40.2, this being the quantity of sperm the candles would have consumed had they continued burning for 10 minutes.

39. *The Governor*.—The construction of a gas governor and the principle of its action are so well known that it will suffice to say that the only peculiarity which the experimental governor possesses is extreme sensitiveness in action. The largest or central pipe is the inlet, the other pipe being, of course, the outlet for the gas. It is mounted on the table, each pipe terminating with a small cock, by opening which water may be drained off, if from any accident it should get into the pipes. A convenient position for the governor is that shown in the frontispiece. The tank must be charged with water to the height of the side plug, when the pipes are open to the atmosphere and the gas shut off. The parts of these sensitive governors which were made by Mr. Hartley in tin are now made in incorrodible porcelain. (Fig. 4a.)

40. *The Pressure Gauge*.—A small syphon gauge may satisfy the letter of the law, but the advantages attendant upon the employment of a King's gauge, such as is shown in Fig. 5 are so great that the latter gauge ought always to form part of a set of photometric instruments. The gauge may be placed in any convenient position on the Photometer table, and its inlet connected to the outlet of a four-way cock, from which pipes are extended to the inlet and to the outlet of the meter, to the inlet of the governor, and to the gas pillar; so that the pressure at any one of these points may be ascertained, and the working state of the instruments in respect to friction or resistance to the passage of gas determined.

41. Besides enabling the operator to detect undue friction, the King's gauge enables him to readjust, when needful,

the consumption of gas to the standard rate without waste of time; for, knowing by experience what pressure should

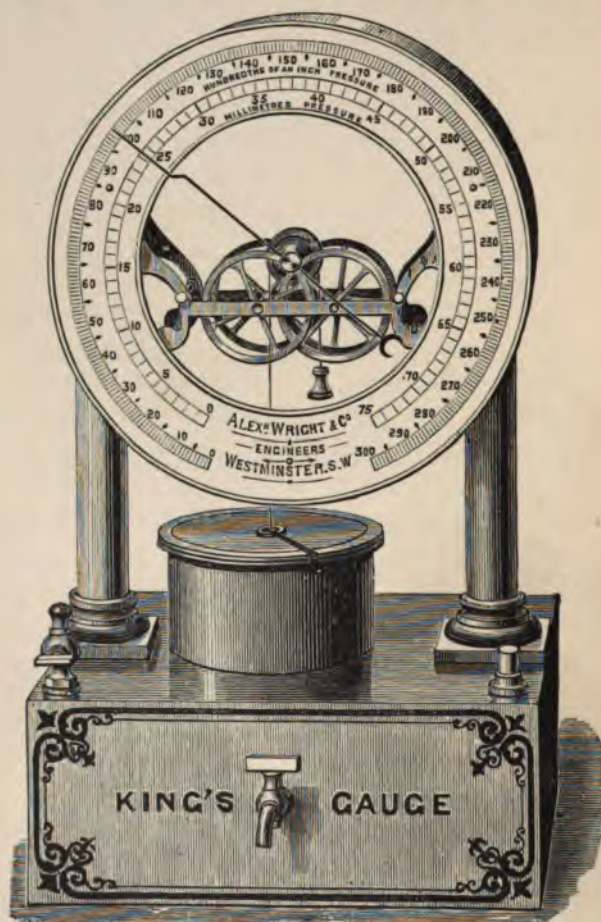


FIG. 5.—KING'S PRESSURE GAUGE.

be below the burner under certain conditions, he may at once turn the adjustment cock on or off to the extent requisite to secure the desired indication of pressure on the

gauge. The base of the gauge consists of a rectangular box, through the centre of which passes a cylinder down to within an eighth of an inch of the bottom, the cylinder being much smaller in area than the space about it within the box. Extending upward from the box are two pillars, which support an arc dial and also two cross bars, one in front and the other at the back. Between the bars is a grooved wheel, fixed on an arbor, which is free to turn on centres or upon antifriction rollers. The arbor also carries a pointer, extending up to the dial. A silk cord



FIG. 6.—SULPHURETTED-HYDROGEN TEST GLASS.

passes over the wheel, and is secured to the latter at one point of its circumference. To one end of the cord a float, which descends into the cylinder, is suspended, while the other end of the cord carries a small weight.

42. The gauge is charged with water, when no gas is entering it and when its vent cock is open, to the height of the socket in front or to the centre of glass bezil; and, if needful, the pointer shifted on the arbor until the former coincides with the zero of the scale. The vent cock is then closed, and if gas be admitted, its pressure will operate

within the box, forcing the water up in the cylinder, thereby causing the float to rise and the wheel above to make part of a revolution and the pointer to traverse over part of the scale, which is greatly enlarged, and indicates to $\frac{1}{100}$ th of an inch of pressure. When this gauge is to form part of a new set of instruments, it is advisable that the maker of the photometric apparatus should furnish the bench or table for the Photometer, fitted complete with the necessary cocks and pipes, as an ordinary gasfitter will scarcely realise what is required.

43. *The Burner.*—The kind of burner to be employed will, as stated in preceding paragraphs, depend upon the obligations imposed upon the gas company.

44. *The Candles.*—These should be of the purest sperm, admixed with a small proportion of wax to "break the grain," and should be obtained from the maker of the highest repute, or from those who act as agents for the sale of such maker's candles. Many candles are sold by shopkeepers as "sperm" which possess no claim to the name.

45. *Bunsen Discs.*—These should be made of paper as thin as it is possible to manipulate, and the line of separation between the greased and ungreased parts should neither be defined with such absolute hardness as to be distinctly visible in every position between two lights, nor be softened down so much that in any one position the spot becomes quite invisible. In the first case it will be difficult to determine the point of equal illumination, owing to the hardness of the separating line; and in the second case, it will be found to be impossible to decide with certainty upon the point of equal illumination, to the extent possibly of at least one candle's power. The second kind of disc cannot be amended, but the first, or hard-line disc, may be easily rendered fit for use by simply passing it rapidly over a gas flame, then trying it, and, if needful, repeating the operation

of slightly warming until it is rendered sufficiently sensitive. The disc must be perfectly flat, for if it bulges out when in its holder and presents a convex surface to one of the flames and a concave surface to the other, the indications obtained will not be correct.

46. Sometimes Leeson star discs are used instead of the Bunsen. The Leeson disc consists of three thicknesses of paper, the outer pieces very thin and the middle one somewhat stouter, with a star-shaped hole cut in its centre. These are all pressed as closely together in the disc holder as possible. The advantage claimed is uniformity in the texture of the surfaces presented to the eye, which certainly is not the case with the Bunsen discs, as the texture of the paper is affected, as well as its colour, by the grease. Mr. Hartley raised several objections to these discs, and at the present time, though occasionally used, they have not much vogue. They are useful in comparing lights of different colors, diminishing, though in a slight degree, the different shades of colour on the surfaces of the disc.

47. *The Glass Vessel, or Testing Glass for Sulphuretted Hydrogen.*—A convenient form of vessel is that shown in Fig. 6, which represents a glass cylinder, the ends of which are closed by a base plate and a cover, both of white metal or porcelain. A pipe, which is attached to the base, passes upward through the cover and terminates with a screwed end, which enters the nut, or cap, which is surmounted by a burner. When the nut is screwed down on the cover it causes the cylinder to be compressed between washers of leather or rubber within the base and cover, and renders the junctions gas-tight. Within the glass are two cups containing water, while immediately above in the cover are two plugs, each furnished with a clip, which serves to hold a test paper of such length that its end dips into the water-cup below. It will be observed that two small jets project from

the pipe within the glass. These must be directly opposite the suspended papers. The gas enters by the vertical pipe, escapes through the jets (the vertical pipe being stopped just above the jets), passes through a hole in the upper part, and thence escapes from the burner. The instrument is made with the outlet pipe in the base when it is desired to pass the gas on to the Photometer burner, or to any other testing instrument, such as the Referees' Test for Sulphur Compounds "other than sulphuretted hydrogen." The time for exposure of the test papers is, under the Gas Works Clauses Amendment Act, three minutes, or such time as may be fixed [par. 15 (a), Part II.], but in London the time of exposure is extended to about twenty hours under conditions which are set forth elsewhere in this treatise.

48. *Service Governor*.—This may be either of the wet or dry kind. It should always be used when the pressure of supply is likely to vary, and to rise much above that of an inch head of water. It should be weighted to give about $\frac{1}{16}$ ths of an inch of pressure, and will then prevent undue strain being thrown upon the experimental governor, and thereby greatly assist in the maintenance of an uniform rate of consumption.

49. *The Barometer*.—Two forms of barometer are here illustrated. Fig. 7, representing the "Standard," which is used when the greatest possible exactness is essential, and Fig. 8, representing the "Pediment" barometer, which is generally employed for purposes which do not demand extreme accuracy. Both barometers consist essentially of a long glass tube, closed at the top, and with its lower end dipping into a cistern of mercury. The tube being entirely free from air, the mercury forms a column within the tube of such height as to give a pressure equal to that which the atmosphere exercises on an equal area of the cistern.



50. When the mercury in the barometer tube falls, that in the cistern rises in corresponding proportion, and *vice versa*, so that there is an ever-varying relation between the level of the mercury in the tube and the mercury in the cistern, which affects the accuracy of the readings. M. Fortin's form of cistern, which is adopted in the Standard barometer, completely obviates this difficulty. The cistern is made of glass, with flexible leather bottom and a brass adjusting screw, as shown in Fig. 9. Through the top of the cistern is inserted a small ivory pointer, the lower end of which corresponds with the zero of the scale; and in order that the readings should possess uniform value, it is necessary that the level of the mercury in the cistern should be adjusted by the screw until the ivory point *appears* to touch its own reflection on the surface. The reading is then taken.

51. In the best kind of "Pediment" barometers, Fig. 8, the variations in the level of the mercury in the cistern are compensated on the scale, each indicated inch of which is less than an inch in length, to an extent proportionate to the relations of *the area* of the tube to the area of the cistern. With this kind of barometer the accuracy of the indications are dependent on the skill and care exercised by the maker in the compensation. Guaranteed instruments should, therefore, only be employed, as many Pediment barometers are made which are not compensated at all, or but imperfectly so. Properly adjusted instruments of this class may be fairly depended upon for all ordinary purposes, gas testings included.

52. The vernier is a movable scale for subdividing parts of a fixed scale. By the aid of this instrument, subdivisions of the scale of the Standard barometer may be made to the 1000th of an inch. Fig. 10 shows the scale of a standard barometer divided into half-tenths, or .05 of an inch. The

vernier, *C, D*, is made equal to 24 of such divisions, and is divided into 25 equal parts, from whence it follows that one division on the scale is $\frac{1}{25}$ th of .05 larger than one on the vernier, so that it shows a difference of .002 of an inch. The vernier reads from .0, or zero, upward; *D*, therefore, indicates the top of the mercurial column. Each division of the vernier showing a difference of .002, it follows that



FIG. 9.—CISTERN OF BAROMETER.

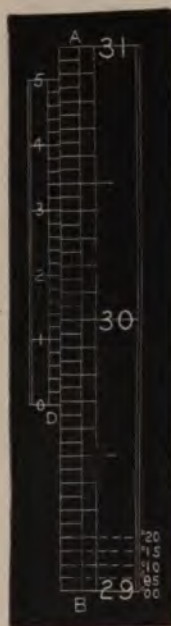


FIG. 10.—VERNIER AND SCALE.

five divisions show a difference of .01, or 100th of an inch; hence, every fifth division is numbered.

53. In Fig. 10 the zero of the vernier is between 29.65 and 29.7 on the scale. Glancing up the vernier and scale, the second line above .03 will be found to coincide with another on the scale; this gives .03 and .004 to add to 29.65, so

that the actual reading is 29.684. In those instances where no line on the vernier is found *precisely* to coincide with a line on the scale, and doubt arises as to which from two are equally coincident, the rule is to take the intermediate 1000th of an inch.

54. A barometer should be suspended in the shade, and should be perfectly vertical, for the slightest angle will increase the apparent height of the mercury column. The Pediment barometer is first prepared for use, after suspension, by applying one of the pinion keys, which is below the scale, to the square-headed screw at the bottom of the instrument, and turning gently to the left until the screw stops. The key is then replaced in its position to operate the vernier.

55. In taking a reading with a Standard barometer, it is important that the eye, the zero edge of the vernier, the top of the mercurial column, and the back of the vernier should be on the same horizontal plane, conditions which practice will render attainable. With Pediment barometers the vernier is in front of the scale, and the zero line of the former must be made to coincide, as nearly as the eye can judge, with the top of the mercurial column.

56. The scale and vernier of a Pediment barometer are seldom divided so minutely as those of the Standard kind, the scales being divided into tenths of an inch, and the verniers made to indicate the 1000ths of an inch, which is done by dividing nine-tenths or eleven-tenths of an inch on the vernier into ten equal parts.

57. In making barometric observations for comparison with others, it is necessary that all should be reduced to a temperature of 32° Fahr., and also with any tube less than 0.6 of an inch diameter to correct the apparent height of the mercury column for capillarity (unless, indeed, the correction for the latter has been made on the scale), but these

refinements are not necessary for photometric purposes, as their effects would be inappreciable.

58. *The Aerorthometer* is the instrument referred to in par. 19. It consists of a mercury chamber, the top of which

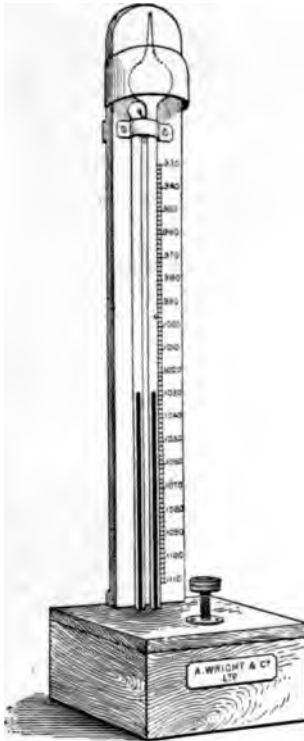


FIG. 11.—AERORTHOMETER.

is flexible, so that the volume of mercury can be adjusted by means of a screw plunger working upon the flexible cover. With this mercury chamber two glass tubes of equal parallel bore communicate. Against these tubes is affixed a scale of Aerorthometer numbers, starting from about 920 at the top and continuing to about 1140 at the bot-

tom, and divided at every second graduation. Now, the left-hand tube is open at the end, and the right-hand one terminates with a bulb, which has a small opening. To set and adjust the instrument, the tabular number representing the barometrical and thermometrical conditions adjacent to the Aerorthometer is carefully taken, and the two mercury columns in the tubes (which will rise equally) are adjusted till they stand about an inch above the Aerorthometer number which represents the same conditions as the tabular number already observed (par. 19). The finger is moistened with a little distilled water and placed gently at the opening of the bulbed end of the right-hand tube. The mercury columns are then allowed to fall to the level of the correct Aerorthometer number, and a little moisture is thus drawn in. The bulbed end is then carefully sealed, means being taken to prevent any heat being communicated to it.

Now, it will be clearly seen that the tension in both tubes is the same when the mercury in each is level.

59. In order to find the Aerorthometer number, the mercury has only to be depressed or raised until the two mercury columns are equal, and the number read. It will be seen that a fall in temperature or a rise in the barometer have both the effect of diminishing the apparent volume of air in the sealed tube (the moisture in which obviates correction for tension of aqueous vapor), and *vice versa*, so that the two columns will be of equal height at different points on the scale, according to the varying combinations of barometer and thermometer.

The Photometer Room.

60. "THE PHOTOMETER ROOM should, for the sake of comfort and convenience, be of reasonable dimensions—that is, about 12 feet square and 9 feet in height. It should be

well ventilated, although free from draughts, not subject to vibrations, and should be maintained at a temperature as near to 60° Fahr. as circumstances will permit. A smaller chamber will *do*, say 8 to 10 feet long and 5 to 6 feet wide, but the operator will, if cramped for space, experience so much discomfort that he will be tempted to hurry over the operations. Besides which, a very small room will not allow comfortably of the presence of a visitor or assistant."

61. "*The Photometric Apparatus* is best placed next one of the walls of the room—on a table, which must be firm and rigid, with its top surface perfectly level, and 2 feet 9 inches above the floor line. In lieu of the table a stout shelf may be fixed along the wall. It should be 24 to 30 inches wide, and at least 8 feet long. The wall behind the table should be coloured dull black with flatted paint, or lampblack and size, to the height of about 2 feet above the table top, or a black cloth may be suspended against the wall. The room should be generally of a somewhat dark color, but need not be blackened all over."

62. It is, unfortunately, the fact that even after all these years little attention seems to have been paid to the all-important question of the dimensions, ventilation, and heating of Photometer rooms, on the importance of which Mr. Hartley, in the above quoted remarks, lays so much stress. Carefully made and accurately adjusted instruments are placed in rooms insufficient in size, badly ventilated, so as to be scarcely capable of supporting the combustion of the opposed lights and of carrying away quickly enough the products of combustion, and so situated as to be sensitive to vibration and to changes in temperature. The effect of these conditions is that gas is apparently deteriorated in quality and is shown to be less than it actually is, with the result that thousands of pounds are expended annually on an enrichment, which is really unnecessary.

63. The question is an important one, and if it is dwelt upon with emphasis, it is because the writer feels that the ease with which satisfactory conditions can be obtained, and the annual saving which such conditions would entail, are not realised by the majority of gas makers. There is no doubt that in nine cases out of ten when a Photometer room is being improvised, a few minutes' thought, a few words of advice from an experienced quarter, and the expenditure of a few pounds would be of inestimable value, and enable a Photometer to be used under natural conditions. It is now recognised that the best conditions for testing are natural conditions, and the writer believes that there is scarcely a gasworks in which a room cannot be arranged in such a manner that the temperature can be automatically adjusted to a suitable point, and the currents of air arranged so that a plentiful supply of fresh air is obtained, and the products extracted without down draught, with the invariable result of an indication on the Photometer of the correct, or, as compared with tests made in an unsuitable room, an increased, illuminating power. For further notes on Photometer rooms see the chapter on the new Table Photometer, pars. 144 to 159.

Fitting Up.

64. Set the apparatus upon the bench or table in the order shown in the frontispiece. Fix the service governor (par. 48) in any convenient position, and from its outlet connect a pipe $\frac{1}{2}$ -inch or $\frac{5}{8}$ -inch bore to the inlet of the Photometer. Connect the outlet of the meter to the inlet of the governor (par. 39), and the outlet of the latter to the pipe below the Photometer. The connections must be of metal pipe, and in most Photometers, such as the one illustrated in Frontispiece, the pipes are already fitted before the instru-

ment is sent out—and are provided with syphon cocks for draining. Charge the various instruments, which require it, with water, put all the weights on the service governor, and remove all the weights or shot from the counterpoise of the experimental governor.

65. Turn on the gas and let it pass freely from the pillar for five to ten minutes, then place a blank cap on same after removing burner, and try all joints for soundness; then afterward observe for a few minutes whether the pointers of the meter dial move. If they do, tighten up all the joints, so that the meter pointers finally remain stationary for a period of at least five minutes. Be careful that each instrument stands perfectly level on a horizontal plane.

66. The sulphuretted hydrogen test (par. 47) may be fixed on the photometer table or on a bracket against the wall, and a gas pipe connected to it.

67. The barometer (par. 49) should be hung against the wall of the room in any convenient position for taking readings.

68. It is advisable that the gas service to the photometric apparatus should extend direct from the main, and be independent of any other lights than one bracket, which should be kept lighted, so as to establish a draught on the main.

Preparation of Candles.

69. The Standard Sperm Candles are $8\frac{1}{4}$ inches long from base to shoulder. Cut each candle in two parts at $4\frac{1}{8}$ inches from its base. This is best done by laying the candle on a clean level surface, and rolling it under the edge of a sharp knife. Cut away half an inch of sperm from the top of the lower half, and also cut away the sperm cone from the top half; reduce the projecting wick of the latter to half an inch in length. Take great care, in cutting away the sperm, not

to injure the wicks in the slightest degree. Burn the pieces of candles not too closely together, in a place free from draughts, until the flames attain their maximum size, and each wick bends over and presents a red point through the flame, then touch it with a piece of sperm and blow out the flame. Always extinguish candles in the way described, and thus preserve their wicks in good condition.

70. If any of the candles burn badly, smoke, form very irregular sperm cups about the wicks, or gutter, reject them, unless they can be made, by judicious treatment, to burn properly. They may sometimes be made to burn with regular cups by paring away the irregular parts. Any candles with their wicks much out of centre should be at once rejected. Store the selected pieces in a place of moderate temperature, and where the wicks will be safe from injury. The following from "Remarks on Photometry," a paper by Mr. Hartley, read before the British Association of Gas Managers, June 8, 1870, expresses some of the characteristics of a good sperm candle:

In respect to the selection of candles for experiment, there are certain appearances about a good sperm candle when burning (and all must be burned preliminarily, to get them into a proper condition for use) which go far to show whether the candle is or is not a fair specimen. These appearances can be much better practically illustrated than described, but the writer may mention some of them. The candle should burn with a shallow cup, and the sperm within an eighth of an inch of the top of the candle should, after it has been burning some time, be firm, and bear a good squeeze between the finger and thumb without yielding to the pressure. The wick should appear somewhat small and compactly woven, and not bend to an exceeding degree out of the upright. Lastly, on looking down into the sperm cup there should appear to be a number of radial dashes (something like the dotted lines in a drawing, but much more irregular) extending from the wick to the circumference. If a candle contains paraffine or stearine, some or all of these

peculiarities are wanting. The cup will be deeper, its edge will soften and give way to a very slight pressure, the wick will be generally larger, and there will be no appearance of radial lines in the sperm cup. The peculiarities mentioned apply in part, however, only to candles which have been made some little time. Candles which are quite new generally burn somewhat irregularly, and the radial dashes in the cup are mostly absent, doubtless owing to a temporary disturbance of molecular arrangement, consequent on the heating of the sperm when the candles are made.

The conditions under which a candle is burned exercise a material influence on the amount of light which it yields, as well as upon the rate of consumption and uniformity of the light. The atmosphere surrounding it should be tranquil, otherwise the candle is almost certain to form an irregular cup, to gutter and to smoke. If in a tranquil atmosphere the candle burns thus irregularly, it is an evidence of its unfitness for photometrical use. The candle may be fairly protected by screens from draughts, but not, the writer thinks, absolutely enclosed in a box, inasmuch as, when so enclosed, the surrounding air may (unless, indeed, the box be enormously capacious) be somewhat heated, the supply be not so free, and the candle be burned, in consequence, under abnormal conditions. Moreover, when so enclosed, its condition is not so readily observed by the operator.

At first the idea of selecting the candles may seem to involve the conclusion that the operator might make the gas to appear good or bad at will; but in fact the selection would have just the contrary effect, and would narrow the boundaries within which errors might be made.

When exactness is required, and especially when tests are made against a gas company, the results of which may subject the company both to pecuniary penalties and to discredit, no photometric estimation of the value of the gas should be accepted which was based upon less than three or even four consecutive experiments with different candles, each experiment lasting for at least ten minutes, so that an operator might easily make the whole test in one hour; or if, as in many country towns, this would involve too much labour, if done in one evening, the examiner might make one trial on each of four evenings in a week, and then the average of the whole would represent the illuminating value for the week.

If, in such a series, one of the experiments should work out very discordantly with the rest, that experiment should be rejected, and a fresh experiment be made, or, if that be not possible, a mean taken from those experiments which were nearer in agreement. Such a practice would go far toward securing agreement between the results of different operators.

71. It is to be remarked that many operators prefer to burn the upper half of the candle from the point at which it is cut toward its apex, the object being to approximate more nearly to uniform light and consumption, for as a candle tapers throughout its length, the lower half is continually increasing its diameter about the wick as it burns down, while the inverted upper half is as continually diminishing. Mr. Hartley, however, used candles in both ways, and preferred that which he has recommended, as the compensation afforded by the other method is more theoretical than real.

Testing Operations.

72. Take the upper and the lower halves of one candle, or the lower half of one and the upper half of another, and place them in the candle holders of the balance, so that at least an inch of each candle projects above the top of its holder. Warm the sperm about the wicks with a lighted taper, and ignite the wicks fully and completely. Let them burn for at least ten minutes (par. 15, Part II.), so that the flames shall attain their maximum size.

73. The candles should be so placed in the holders that their wicks should bend away at right angles with each other. By this arrangement the centres of the flames will be made to coincide with the terminal point of the Photometer. Some operators place the candles so that the line of bending of the wicks shall be parallel with the line of the bar, but

with one wick bending over toward and the other bending away from the disc; but this plan is not so good as the one recommended.

74. The position of the wicks relative to the disc or bar is very important, for if the points of both wicks are turned toward the disc, the gas will be prejudiced, and if both are turned away from the disc, the apparent value of the gas will be unduly exalted in the comparisons, because in the first case the true centres of the flames will be nearer to and in the second case farther from the gas flame than they ought to be.

75. The adjustment of the gas to the 5-cubic-feet rate per hour may be effected while the candles are preliminarily burning, especially if only one minute-clock be had for timing the rates of consumption, both of the gas and of the candles.

76. At the outset ascertain whether the meter, the governor or governors, and also the gauge are properly charged with water. The water-level of each of these instruments must be examined, and, if needful, readjusted at least as often as at intervals of 7 days, especially the water-levels of the meter and gauge. (See par. 37.) Turn on the gas and weight the service governor to give about $\frac{1}{16}$ ths of an inch pressure. Screw on the burner, which, in the absence of any obligation to the contrary, should be, for common gas, a No. 1 London Argand; use with the size of chimney which will give the best result (par. 13), which will be ascertained on trial. Clean the chimney thoroughly before placing it on the burner, and do so on every after occasion before commencing the testings. Fully open the regulating cock. Place as many of the loose brass weights or shot upon the counterbalance suspended from the beam of the experimental governor as will cause the gas to be delivered from the burner at the

rate of about $5\frac{1}{2}$ cubic feet per hour. In this and in the after operations the sliding weight on the governor beam may be used with advantage.

77. When the rate of delivery is sufficiently reduced, operate with the regulating cock until the long pointer of the meter makes exactly one revolution per minute. This may take some time, but, all conditions as to pressure remaining constant, the cock will need but little motion after it is once set. It should be noted that the regulating cock when fixed need not be disturbed; the gas can be turned off from the Photometer by means of the inlet cock. When the pressure at point of ignition has been found on the King's gauge, so that 5 feet per hour is being delivered, the King's gauge indication is noted, and any adjustment of the cock to bring the pointer to this will be found to save time, and render the taking of the meter rate only a question of confirmation, subject, of course, to the slight variations caused by change in specific gravity. In order to obtain this result, care must be taken to keep the water-level of the meter constant, and also that the pointer of the King's gauge with no gas upon it and the vent cock open is at zero.

78. Until quite familiar with the operations, it is best to start with both clock and meter at zero. Raise the stopping lever of the clock, press smartly on the top button, and the clock hands will fly to zero. Turn the long pointer of the meter back until it is upright. Release, and as soon as the long pointer reaches the figure 5, swiftly press down the side lever of the clock.

79. Let both run for ten minutes, at the end of which time note the position of the meter hands, as explained in pars. 29 to 32. Take every care to secure 5-feet rate. Small divergences, such as 4.9 or 5.1, may be permitted and corrected for, but much greater ones should not be permitted. After the operator has had experience as to the



reliability of the meter a one-minute observation will suffice, to be checked again after the ten readings of the disc are over, and the candles have burned the time observed. Generally speaking, it will be found that if the meter goes at an equal speed for three successive revolutions, it can be relied upon to give the correct rate by one minute's observation.

80. In every case burn the gas for fifteen minutes before making any testings for illuminating power.

81. Turn next to the candles. If they have burned down much, push them up until fully an inch projects above the holders. Stop the clock, and set it again at zero. Nearly counterpoise the candles with weights, shot, or glass beads, leaving the candles a trifle heavier than the counterpoise. Watch the balance until the candles and the opposing weights become equipoised, and the pointer of the balance reaches the centre of its index. Instantly start the clock. Place 40 grains in the pan of the candle holders, and proceed to make observations of the relative illuminating power of the gas and candles.

Readings.

82. Move the slide carrying the Photometer disc between the gas and candle flames until a position is reached at which the spot on the disc is nearly invisible, or both sides are equally illuminated. Observe the graduation (pars. 23 and 24) on which the pointer of the slide rests, and record on paper. It is advisable not to observe the bar while moving the disc box, as the judgment as to the equality of the illuminated surfaces of the disc is easily influenced by the unconscious bias caused by observation of the bar. Make ten such observations within ten minutes (reversing the disc after the fifth reading), then give entire at-

tention to the candle balance, and when it again turns and its pointer reaches the centre of the scale, stop the clock, and note on paper the number of minutes and seconds during which 40 grains of sperm were burned. It will be seen that if the first observation of the bar is made at the beginning of the first minute, the tenth and last observation will be made at the end of the ninth minute, leaving the last minute free for watching and timing the turn of the candle balance.

83. It is to be observed that some little practice is necessary to determine the position of equal illumination of the disc, for, owing to the difference in the colour of the lights usually contrasted, the difference in the texture of the greased and ungreased parts of the disc, etc., the spot seldom becomes invisible; but experience soon enables the operator to decide with certainty respecting equality of illumination (par. 45). The references to the Referees in the following paragraphs are to their instructions previous to 1898, at which date the Table Photometer was adopted.

$$\begin{array}{r}
 8.6 \\
 8.4 \\
 8.5 \\
 8.5 \\
 8.6 \\
 8.6 \\
 8.5 \\
 8.6 \\
 8.7 \\
 8.6 \\
 \hline
 10)85.6 \\
 \underline{8.56} \\
 2 \\
 \underline{17.12}
 \end{array}$$

84. Supposing the ten consecutive readings of illuminating power to be as above, the mean is 8.56, which, multiplied by two, as two candles are employed, indicates an illuminating power for the gas of 17.12 candles.



85. Such a result as that just indicated would only be accepted as correct under the following conditions—namely:

That the gas had been burned at the rate of exactly 5 cubic feet per hour.

That the candles had burned at the rate of 120 grains each per hour, or that the two had burned 40 grains in ten minutes.

That the height of barometer had been 30 inches and the temperature 60° F., the temperature to be taken being that of the gas passing from the meter, and not that of the air.

86. Too much care cannot be exercised in adjusting the gas consumption to the exact 5-cubic-feet rate; but supposing that the rate was found to be 4.9, instead of 5 cubic feet (par. 31), then correction must be made. The Referees make no mention of a correction of this kind, but direct that “the rate of burning of the gas shall be 5 cubic feet per hour—a rate of consumption which is shown by the hand of the meter making exactly one revolution per minute for several minutes consecutively.”

Correction for Gas Consumption.

87. Multiply the average illuminating power by 5, and divide by the actual rate of burning.

Example:

Average of readings	17.12
Standard rate	5
Actual do.	4.9)85.60
Corrected average	17.46

88. The range allowed in the consumption of the candles (par. 10) corresponds very nearly for two candles with the burning of 40 grains in $10\frac{1}{2}$ minutes for the lowest rate, and with $9\frac{1}{2}$ minutes for the highest rate.

Correction for Candles' Consumption.

89. Multiply the average illuminating power (after any needful correction for gas) by the time in seconds due to the Standard rate, and divide the product by the actual time of burning.

Example:

Corrected average for gas consumpt. as per	
par. 87.....	17.46
Time due to 40 grains, in seconds.....	600
Time actually occupied, say	
9 min. 34 secs., = secs.....	574
	10476.00(18.25
Corrected average.....	18.25 candles.

Corrections for Barometric Pressure and Temperature.

90. Divide the corrected average last obtained by the number which is in the Table D of Appendix, in line with the observed barometric pressure and under the observed temperature, which last must be that of the gas, as stated in par. 85.

Example:

Corrected average as above	18.25
Bar. 30.3. Temp. 52°. Tab. No., 1030.	
1030)18250(17.71 candles.	

91. In the first edition of "Photometry," which Mr. Hartley published early in 1871, he states that it is not sufficient, when exactness is demanded, which is the case when the illuminating power of the gas is sought for scientific purposes, or when it is sought for the purpose of ascertaining whether a gas company is fulfilling its obligations to the public, to deduce its illuminating power from any *one set* of ten observations, or from repeated sets of

observations, against the light produced by the *same* candle or the *same* pair of candles; the gas light should be compared against the light of *different* candles or pairs of candles, and the apparent illuminating value be taken as equal to the mean of the whole series of observations. The Referees require each gas examiner to make *three tests* daily, but say nothing about using different candles in each testing.

92. When done with for the time being, extinguish the candles (par. 69), taking care to preserve the wicks in good condition. Leave the regulating cock and governor in adjustment, and turn down or turn off the gas to the Photometer by means of the inlet cock to the right of the table.

93. The above is a good method of making the calculations for a test. They may be shortened by use of Hartley's Rules and Tables (see Appendices A, B, and C, with examples). Another method of making the calculations is embodied in Mr. J. A. Coombs' Photometrical Tables (Logarithmic), which are very simple and complete, and will be found in Appendix F, with example. Attention is also directed to Appendix J, which embodies the substance of the Gas Referees' instructions prior to the adoption of Harcourt's Table Photometer in London. This is not now in operation, but is inserted for purposes of reference. The rules given in paragraphs 84 to 90 are, however, all that are necessary to make the calculations; the others are alternative methods.

Some Possible Difficulties.

94. The operations of setting up, testing, adjusting, and making a test by a Photometer have now been described, but it will be as well to recapitulate here a few points, the

observance of which may lessen the possibility of any difficulties occurring during a test.

1. See that the Photometer is sound (par. 65).
2. That there is no water in the pipes (par. 64).
3. That you have not too great pressure (par. 76), and that
4. The balance governor is in nice adjustment (par. 76).
5. Be certain that the pressure at point of ignition is right (pars. 41 and 77).
6. Work with a clean chimney (par. 76).
7. Have a good stock of tested candles kept in a cool, dry place.
8. Be sure the waterline of the meter is correct. Do not go by the mark on the glass; test it by cubic foot or one-twelfth cubic foot bottle (par. 37). A test of illuminating power should not be made until the water in the various instruments, particularly the meter, is saturated with gas.
9. See that the clock is wound up (par. 38).
10. Keep candle balance in good condition.
11. Burn the gas for fifteen minutes, at least, before making a test.

There are other causes of error which are so obvious that they need not be dwelt upon, but if due regard is given to the points above, and to the proper arrangement of the Photometer room, so as to render it independent of outside conditions, consistent and accurate results should be obtained. The question of the proper supply of air to the Argand burner is a most important one, and extended reference is made to this and other points in the chapter on the Harcourt Table Photometer which follows.

The Inferential or Jet Photometer.

95. The late Mr. George Lowe is entitled to the credit of having applied the jet Photometer as a constant indicator of the quality of the gas being manufactured. For this

purpose it is invaluable to the gas maker; a moment's inspection of the height of the jet flame, produced under a constant pressure, indicating to him whether the gas is sufficiently good in quality, and if not, the necessity of an immediate investigation and the adoption of remedial measures. Doubtless other engineers also applied the jet in a similar manner and for the same purpose, but there is reason for believing that their contrivances were less perfect than Mr. Lowe's, and that they attached less importance to the indications of the instrument than that gentleman did.

96. The jet Photometer is represented in Fig. 12. It is a delicately constructed King's gauge, similar to that described in par. 40, but it is surmounted by a steatite jet burner, in front of and behind which are glass plates, graduated upward from the level of the burner top into inches and tenths of an inch. Some Photometers are made with only a mark at 7" from tip of steatite jet. These are difficult to re-rate, as will be seen from paragraph 98, therefore the scales described above are best, because they can be rated in 10 minutes by any one who has a bar Photometer. The gauge is enclosed in a glazed wood case, having a copper chimney on its top. On one side of the case two dry governors are fixed, through both of which the gas passes, the second one being weighted to give a lesser pressure than the first. From the outlet of the second governor the gas is conducted through a pipe, furnished with a regulating cock, to the gauge. By these appliances the gas pressure is readily adjusted, and its regularity maintained. On the opposite side of the box a water cistern is fixed, and by means of a three-way cock beneath water may be admitted into or allowed to escape from the gauge. In some jet Photometers an external plunger, as a water-level adjuster, is provided, and the level in the gauge is raised or lowered by screwing down or relieving the piston. In

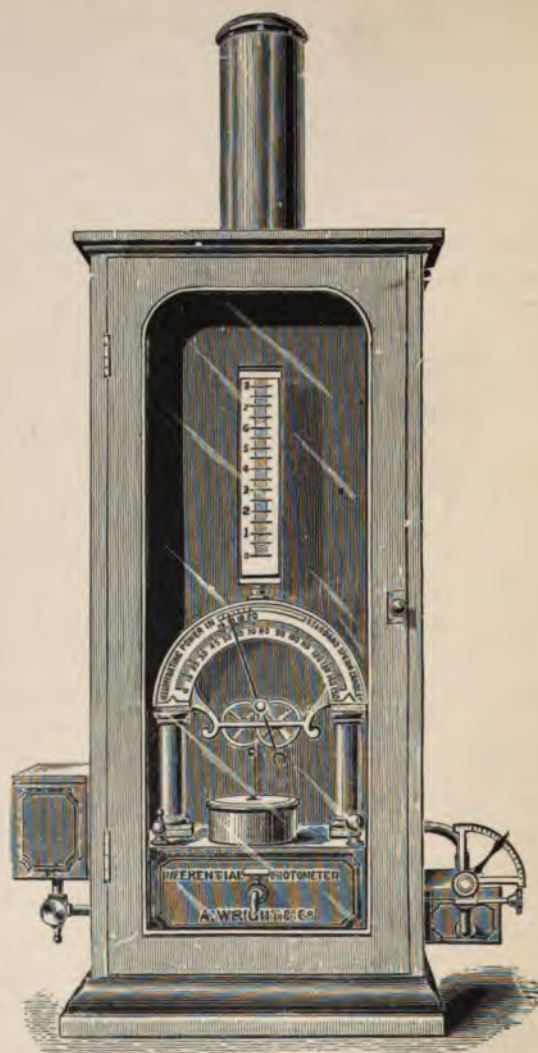


FIG. 12.—JET PHOTOMETER.

some cases also the gauge is made in porcelain, instead of tin, so that frequent repairs are avoided.

To Set the Jet Photometer at Work.

97. Set the instrument on a firm and level base or support. Carefully remove the float and the packing paper from the cylinder. Replace the float in the cylinder, so that its cord lies in the front groove of the wheel above it. Pass the cord of the weight round the back groove of the wheel, and let the weight hang in opposition to the float. Take care not to strain the cords. Attach a gas-supply pipe to the inlet of the governor. Pour water gently into the cylinder until the pointer exactly reaches the zero of the pressure scale. If too much water be put in, draw off the necessary quantity from the side cock. Turn on the gas, ignite it at the jet, and apply a sufficient number of shot or of pieces of metal to the second diaphragm of the double governor to cause the gauge to indicate, say, $\frac{1}{10}$ ths or $\frac{1}{100}$ ths pressure. Put the glass scales in their position behind and before the burner, and make any further reduction which may be needed in pressure by the aid of the cock or valve at the side of the instrument. Readjust the water-level once a day. When adjustments of water-level are made the gas must be shut off and the vent cock on the gauge opened to the atmosphere. It is important that the gauge is set to zero every day. The jet Photometer should never be connected with flexible tube; tin pipe can, however, be used.

Rating a Jet Photometer.

98. The instruments as sent out are rated, *i.e.*, the length of flame corresponding to a certain quality of gas delivered under certain pressures has been determined. As, however, from various causes, the indications of the jet Photometer are likely to change after some time of use, it is advisable to have it re-rated at intervals. To do this, place the jet

Photometer on a solid bench or table in the room which contains the Bunsen Photometer, connect the instrument, as before directed, to the service pipe from which the gas is supplied to the Bunsen Photometer. Make ten observations with the Bunsen Photometer, and as nearly simultaneously as possible with each of the observations note the length of the jet flame and the acting pressure. Take the mean of the lengths of the jet flame and record it in a book, together with the mean of the pressure, if necessary. The pressure should not, however, vary. Record also the illuminating power of the gas as determined by the Bunsen Photometer. The rating can only be done by instruments having a graduated glass scale for the flame measurement. It is obviously a simple thing to rate under these circumstances, and when the illuminating powers are marked on the pressure scale, as follows:—

- (a) See that water-level of gauge brings pointer to zero.
- (b) Take corrected reading of illuminating power on bar Photometer.
- (c) Turn on regulating cock of jet until the pointer stands at that illuminating power as marked on pressure scale.
- (d) Note height of flame.
- (e) Suppose the height is $6\frac{1}{2}$ inches. Then when it is required to find illuminating power by the jet, open tap till flame is $6\frac{1}{2}$ inches, and read illuminating power on the dial.

The alternative to this method is to open or close jet orifice—an obviously difficult matter.

99. *The Illuminating Power Meter.*—In about the year 1876 Mr. Sugg introduced this instrument, which undoubtedly is a very useful one. It is based on the principle that if a 3-inch flame in a Standard London Argand burner is maintained by gas passing at the rate of 5 feet per hour, the quality of the gas is 16 candle-power, the candle-power

varying, according to the rate at which the gas under test passes, in order to keep a certain constant flame. The principle, it will be seen, is the same as a jet Photometer, for in a jet Photometer the quality is proportionate to the pressure necessary to maintain a 7-inch jet, and since a given pressure is equivalent to a given consumption, the method is the same, though applied in the one case to an Argand burner and in the other to a jet flame. It is much easier, however, to adjust the flame in the jet than to accurately gauge the flame of an Argand burner.

100. Now, both these methods are subject to the same objection—namely, that they are only inferential tests, based upon the diffusive power of gas through fixed apertures, and fall to the ground if there is a variation in the relation between the specific gravity and the illuminating power of the gas to be tested. Now that water-gas is largely used, it has been found that this relation, which was supposed to be a fixed one, is upset; and with pure water-gas or water-gas mixed with coal-gas a 3-inch Argand flame at 5 feet per hour does not represent 16-candle gas, and a 7-inch jet flame with .625 pressure does not represent 16-candle gas. The jet Photometer and the illuminating power meter, therefore, are not only useless where water-gas is made, but absolutely harmful, as their indications are unreliable.

101. **The Rapid-Reading Photometer.*—To meet the want for a quick test (where water-gas is used) such as could formerly have been made on the jet or the illuminating power meter, the rapid-reading Photometer has been introduced. It is illustrated in Fig. 13, and a brief explanation will suffice. It is an ordinary 60-inch Letheby Photometer encased, but in such a manner that the length, depth, and width dimensions are the same as a Standard Photometer,

*See *Journal of Gas-Lighting*, Vol. LXXIII., page 792, March 28, 1899.

and there is free ventilation. The object of enclosing is, that it can be placed in the works just as a jet Photometer. At one end is a Standard Argand burner, at the other end Simmance's Pentane Standard. The gas supply to the burner passes through an experimental meter, showing hourly rate by one minute's observation and a sensitive balance governor. The cocks governing the supply are outside the Photometer. The method of testing is to light the Argand burner, and adjust the rate to 5 feet per hour at the beginning of the day, and to light the Pentane Standard, the adjustment of which is a simple matter (see par. 189). The rate being adjusted, a reading can be taken by an ordinary workman, and the make kept up to the Standard. The Argand can be burning constantly, and its rate occasionally checked; while the Pentane Standard can be kept turned down and instantly turned up when it is desired to take a reading. To obviate trouble in adjusting the rate, the Table G in Appendix is provided with each Photometer, so as to give the corrected illuminating power.

It will be seen that the management of this Photometer requires no more skill than a jet Photometer or illuminating power meter, while the results are as accurate as those given by a Standard Photometer. As a 1-candle Standard is used, a very small quantity of Pentane is required.

Simmance and Abady's Patent "Illuminating Effect" Photometer.

102. The writer makes no apology for here referring to and describing a Photometer for which he and Mr. John F. Simmance are jointly responsible. It is called the "Illuminating Effect" Photometer, and is primarily intended,



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First, for ascertaining with accuracy the efficiency of the lighting in any part of a room or building;
 Second, for ascertaining with accuracy the light given by street lamps, whether electric incandescent or arc, or gas incandescent, open-flame, or regenerative, and for oil lamps of any description or power and when fixed in the streets.

03. A reference to the illustration, Fig. 14, will make the explanation. A small chamber, $16'' \times 12'' \times 2' 6''$

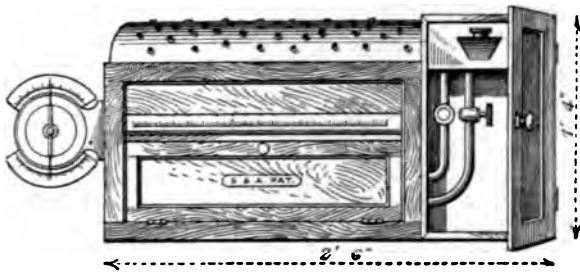


FIG. 14.—ILLUMINATING EFFECT PHOTOMETER.

out), ventilated in such a manner as to permit sufficient currents to support the combustion of a Simmance's Pentane burner, is fitted with a narrow coloured glass front, graduated in inches and tenths from the disc centre. Inside box is placed a running carriage, capable of being moved a handle outside, and bearing the Pentane burner of Simmance's 1-candle Standard. The carburetter of this (which takes in its own air by gravity) is partly outside the box, the air inlet is inside, so that the air taken in is free from turbulence in its rate by the blowing of wind, etc. Between opposite end of the box and the disc is a piece of clear glass, so that the chamber in which the standard of light is placed is free from all outside influences, and the burner is steady in a hurricane as it is in the still air of a room. This standard, the power of which in the ordinary way is

regulated to a fixed height of flame gauge, is standardised by comparison through the glass end with a 10-candle Harcourt lamp, and the height of flame fixed accordingly, and the height gauge adjusted. The height gauge support and the centre of the flame serve as the guide to distance measurement of the standard, its position being read by vertical alignment of these two with the graduation on the coloured glass front. Its height is adjusted by a cock outside the chamber.

104. The disc carrier is fitted in the oblique end of the chamber, and it revolves, as do the mirrors which are fitted in the usual manner. The disc carrier revolves around two quadrants, one showing the angle from the vertical, and the other showing the point of equalisation of the angle of the disc between the light to be tested and the standard of light. Thus, if the disc were set at 60° on the lower quadrant (showing that the light to be tested were 60° from vertical), then by turning the disc until it were set to 60° mark on the upper quadrant, it would be at the correct angle of equalisation, and in the true position for taking a reading. In order to focus the light to be tested on the disc, a mirror is used, which slips over the disc itself and is at such an angle to the back mirror as to throw an image reflected in its centre to the centre of the back mirror. The procedure then is as follows:—

105. Suppose it is required to test the light from a street lamp, say, at a distance of 10 feet. Move the Photometer (it is placed on trestles or a light carriage for street work) till the disc is about this distance from the base of the column. Lift up the door, open inlet tap of Pentane carburetter and light Pentane burner. Close the door. Put the mirror over the disc. Turn the disc carrier until the image of the source of light under test is reflected in the centre of the back mirror. Uncover the disc by removing the mirror.

Note indication on lower quadrant. Say it be 60° . Set to the 60° mark on the upper quadrant. This upper quadrant is marked, not according to the angle, but according to the equal division of the angle. Thus, the 60° mark is at the

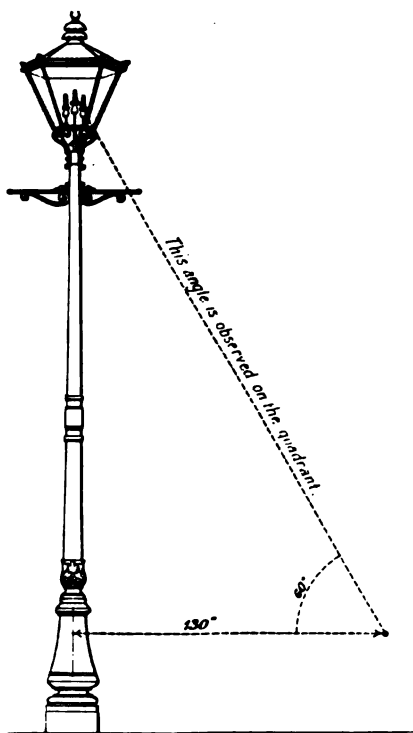


FIG. 15.—SKETCH SHOWING ANGLE MEASUREMENT.

30° division. Adjust height of Pentane flame to height gauge, and move this by winch handle until equality is observed on disc. Measure accurately distance of disc centre from centre of lamp column in a horizontal line—say it is 130 inches. Note position of Pentane burner—say it is 10 inches, *i.e.*, 10 inches from disc centre. (See Fig. 15.)

106. We now have the following data:—

Angle (of a right-angled triangle).....	60°
Distance (base of a right-angled triangle)...	130"
Distance of 1 candle burner from disc.....	10"

It is required to find square of the hypotenuse of the triangle (*i.e.*, distance of lamp being tested to centre of disc), and to divide this by square of the distance of standard of light from disc. This gives the illuminating effect of the burner, and is facilitated by the Table K in Appendix, which gives figures by which the square of the base being multiplied gives the square of the hypotenuse.

To work out the above example:

Square of base, $130^2 \times 4$ (figure in table for 60°) $\div 10^2$;
that is, $67,600 \div 100 = 676$; that is, 676 candles is
effect of light under test.

107. The whole test from first lighting up the Photometer can be done in five minutes. A table of squares which, in addition to the table referred to above, accompanies each instrument (see Table K in Appendix) saves practically all calculation. The use of the equal division of angles by the specially graduated quadrant described in par. 105 is to render the calculations subject to the simple *law of inverse squares* (par. 2), instead of to the cosine law, viz.: that "*The intensity of illumination which is received obliquely is proportional to the cosine of the angle which the luminous rays make with the normal to the illuminated surface.*" In this manner any angle can be ascertained, and therefore any hypotenuse calculated; and the Photometer being quite independent of outside conditions, and the standard of light absolutely reliable it is believed that a new field for photometrical experiment of a strictly utilitarian nature, which has hitherto been neglected, is opened. Comparisons

between different systems of street lighting and indoor illumination can be made in a manner with which the greatest stickler for accuracy cannot find fault, and that without any special knowledge or finesse being required.

108. Attention is directed to the following appendices, some of which are referred to in the preceding chapter, and which will be found useful for reference:—

- Table A. Four rules as to Photometry.
- Table B. Multipliers for correction of rate.
- Table C. Table of sperm consumption and correction.
- Table D. Tabular numbers.
- Table E. Form for recording tests.
- Table F. Coombs's logarithmic photometrical tables.
- Table G. Rapid-reading Photometer tables (Simman & Abady).
- Table H. Harcourt Photometer, 16 candles "result" tables (Gas Referees').
- Table H₁. Harcourt Photometer, 14 candles "result" tables (Simman & Abady).
- Table H₂. Harcourt Photometer, 15 candles "result" tables (Simman & Abady).
- Table H₃. Harcourt Photometer, 17 candles "result" tables (Simman & Abady).
- Table H₄. Harcourt Photometer, 18 candles "result" tables (Simman & Abady).
- Table H₅. Harcourt Photometer, 19 candles "result" tables (Simman & Abady).
- Table H₆. Harcourt Photometer, 20 candles "result" tables (Simman & Abady).
- Table J. Referees' old instructions.
- Table K. Illuminating effect Photometer tables (Simman & Abady).

109. *Verification of Photometers.*—It is well known that the Standards Department of the Board of Trade has laid down very useful rules defining the principal important points in dimension and construction which a Photometer should have, and the department accordingly examines, verifies, and if correct, stamps, Photometers and the instruments.

making them "Standard." The writer has been much impressed with the utility of the Harcourt Table Photometer (of which the Standards Department had, owing to its recent introduction, taken no cognisance), and in order to facilitate its use for gases of other than "16 candles" reputed quality, has arranged it specially for testing various qualities of gas, within a range of from 14 to 20 candles in such a manner that the use of the Photometer out of London is made a very simple matter. The Tables H_1 to H_6 prepared by Mr. Simmance and the writer, further facilitate the testing operations; but there remained one point of importance, viz., the standardising of the Photometer by the Standards Department. The writer has accordingly made representations to Mr. H. J. Chaney, the Warden, and is bound to say with pleasure that that gentleman went most fully into the matter, and as a result, has recently issued departmental regulations enabling a Harcourt Photometer for the Provinces to be examined as carefully as those for use in London are by the Referees. The seal of the Standards Department can thus be obtained for either an open, closed, or Harcourt Photometer. It might be well to state here that there are certain obligations upon local authorities with respect to the periodical re-verification of Standard measures. It is advisable in all cases to have this carried out at the end of every five years.



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CHAPTER II.

*TABLE PHOTOMETER AND THE
PHOTOMETER ROOM**ON THE REDUCTION OF ILLUMINATING
POWER OF GAS*

usion is made in the preceding chapter (par.
m of Photometry prescribed by the Metropol-
tees for use officially in London and used un-
here. The system is sufficiently important to
notice, and therefore this chapter is devoted
on and consideration.

pparatus and mode of testing differ from a
n Photometer in the following particulars:—

	LETHEBY-BUNSEN.	TABLE PHOTOMETER.
ht.	Sperm Candles (fixed).	Harcourt's Pentane 10-Candle Lamp (fixed).
	According to Act (fixed).	According to Act (fixed).
g Gas.	Fixed 5 Feet Per Hour Rate.	Varying to Produce Equality on Translucent Screen.
	Bunsen Disc.	Screened Paper, Carried in Photoped.
Read- inating	Disc is Moved on Graduated Bar Until Equality is Observed.	Distances from Stand-ard Lamp and Burner to Photoped fixed; Height of Flame of Burner Varied until Equal Illumination of Screened Paper in Photoped is Ob-served.

It will be seen that, as the position of the two compared lights and the surface of comparison are all fixed at such distances as are proportionate to the reputed quality, it is only necessary, in order to make a test, to vary the rate of the gas consumed by the burner, and to calculate the correct illuminating power according to the rate of gas consumption. It is obvious that if it is found necessary, in order to obtain equality of illumination, to burn the gas at a rate *greater* than 5 feet per hour the quality is *below* normal, and if at a rate *less* than 5 feet per hour the quality is *above* normal. A correction is made for atmospheric pressure and temperature of the gas.

112. The method of thus varying the rate is recommended by the Board of Trade Committee on Photometric Standards, which reported in 1895, the following being the text of their report on this particular point:—

“13. We further recommend that the illuminating power of coal gas shall continue to be recorded, as heretofore, in terms of the light given by a specified number of cubic feet (to wit, five cubic feet) burnt per hour from the Standard London Argand burner; but that, in testing the illuminating power of the gas, the requirement that the gas shall actually be consumed at this rate be rescinded, so as to allow the Gas Referees to sanction a mode of testing in which the gas shall be burned from the Standard London Argand burner, at whatever rate is found requisite, in order that it may give a light equal to that of the requisite number of candles, and in which the illuminative value of the gas shall be calculated as being inversely as the rate at which such gas had to be burned during the testing so as to give this amount of light.”

113. THE TABLE PHOTOMETER—then, is constructed on absolutely different lines to the Letheby-Bunsen, although the relative strength of the opposed lights is measured inversely according to the square of their relative distances

from the surface of comparison. The Photometer is similar to the instruments of Bouguer and Foucault, and is a modified form of that made by Mr. Hartley for Mr. Vernon Harcourt when the experiments were made with the Pentane air unit many years ago. The description which follows is that of a Photometer for testing 16-candle gas, the necessary slight modifications for testing gas of other qualities being described in par. 130.

Description of the Table Photometer (Fig. 17).

1. The Photometer Table, with its Screens and Mirrors.
2. The Photoped.
3. The Pentane 10-Candle Lamp and Pentane.
4. The Standard Burner and Pillar.
5. The Measuring Rods.
6. The Quadrant or Regulating Tap.
7. The Experimental Meter.
8. The Minute Clock.
9. The Experimental Governor.
10. The Connecting Pipes.
11. The Aerorthometer.
12. The one-twelfth Cubic Foot Bottle.

114. THE PHOTOMETER TABLE, SCREENS AND MIRRORS.

—The sketch, Fig. 17, shows the Photometer in plan, with the various parts marked. The table is perfectly plain, being smooth, level, and dull black, and it measures $5'6'' \times 3'6'' \times 2'5''$ high. The top is solid, and has no holes through it whatever. Upon it are placed, in the positions shown, the Photoped, the 10-candle lamp, the Argand burner, forming a triangle, with the Photoped at its apex and with its sides, respectively, 1000 millimetres, 522 millimetres and 1265 millimetres long. The distances at which the lamp and the burner are fixed from the Photoped, viz., 1000 and 1265 millimetres, are based upon the law referred to in

par. 4. Thus, the lamp being of 10 candle-power and burner of 16 candle-power (given 5-foot rate), the square root of 1000 (1,000,000) divided into the square of 1265 (1,579,225) equals practically 16. By varying the rate of gas consumption the power of the burner at the 1265 millimetre distance is constant, and so the illuminating power or quality of the flame varies inversely as the rate of gas consumption required.

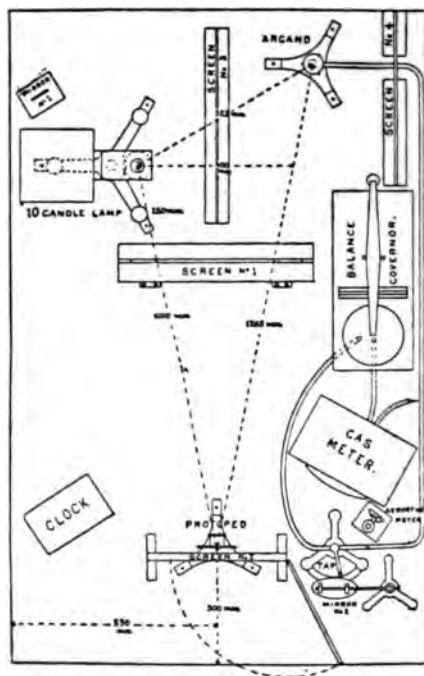


FIG. 17.—PLAN OF HARCOURT PHOTOMETER.

(see pars. 111 and 112). It is necessary to prevent other sources of light from interfering with the accuracy of the results, and so five screens are provided.

115. *The first screen* (No. 1, in Fig. 17) is placed between the burners and the Photoped. It is dead black

consists of a thin mahogany panel, carried on a wooden foot which is hinged to the table, and it is provided with suitable apertures through which the rays of light from the lamp and the burner pass.

116. *The second screen* (No. 2, in Fig. 17) is placed between the observer and the Photoped. It consists of a wooden foot carrying a frame on which a piece of black velvet or cloth is stretched, and in which is cut a hole 50 millimetres square, through which observations are made. At the right hand of the frame is hinged another frame, also covered with black velvet or cloth, and this serves to prevent reflection from the dial of the meter or the arc from interfering with the reading. By means of this screen the observer's eyes are shielded from all light until it is required to make a reading.

117. *The third screen* (No. 3, in Fig. 17) is also dead black, and consists of a thin mahogany panel carried on a wooden foot, and is placed on the table between the lamp and the burner.

118. *The fourth screen* (No. 4, in Fig. 17) is also dead black, and consists of a thin mahogany panel carried on a wooden foot, and is placed on the table at the right-hand side of the Argand burner, as shown in plan. The screens Nos. 3 and 4 stand 6" from the surface of the table, having recently been modified so as to allow a free air supply to the burner. (See par. 152.)

119. *The fifth screen* is not shown in the plan, but it consists of a piece of black velvet or cloth, either carried in a frame or hung on a wall, so as to form a dark background to the lamp and the burner, as viewed from the Photoped end of the Photometer from which observations are made. It should not be less than 300 millimetres behind the flame of the Argand burner.

120. *The two small mirrors* are shown in plan, one near

the 10-candle lamp and the other near the quadrant tap. The first is flat and is clamped to a vertical pillar, and is so placed that the observer can from the Photoped end of the table see the reflection of the height of the flame of lamp, as seen through the mica window which forms part of same. The second one is convex, with a suitable radius of curvature. By its means light can be reflected at will upon the dial of quadrant tap, or the dial of the meter, enabling the observations to be made with ease. All the apparatus on the table, whether wood or metal, is finished in dull black, to prevent all possibility of reflection upon the Photoped.

121. THE PHOTOPED (Fig. 18) is the part of the Photometer in which is fixed the translucent screen referred to in par. 111. It consists of a brass pillar mounted upon a foot which is clamped in position by three shaped clamps, and which, not being attached to the foot itself, allow of the Photoped being adjusted to its proper position on the table. At the upper end of the brass pillar is a flat metal plate about 100 millimetres square, with a central hole 21 millimetres square. *The centre of the square is 400 millimetres above the table.* To the face of this plate is clamped centrally a smaller plate carrying a horizontal tube 35 millimetres in diameter and of suitable length. The clamping of these two plates serves to hold the piece of white paper, unglazed, of fine grain, and free from water-marks. This paper, to which passing reference is now made, fulfils the part that the disc takes in a Bunsen Photometer. Sliding inside the horizontal tube is another tube containing a diaphragm of thin metal, in which a rectangular slot 25×7 millimetres has been cut. Now the rays of light from the lamp and the burner are thrown upon the paper clamped in the Photoped, but have first to pass through the rectangular slit in the diaphragm, thus being projected in two separate bands of light upon the paper. It will be obvious that by sliding the



THE TABLE PHOTOMETER.

65

the containing the diaphragm in or out these two bands of light can be so intersected as to neither overlap nor leave any unilluminated space between them. The reason for this will be apparent on referring to par. 142. The plan (Fig.

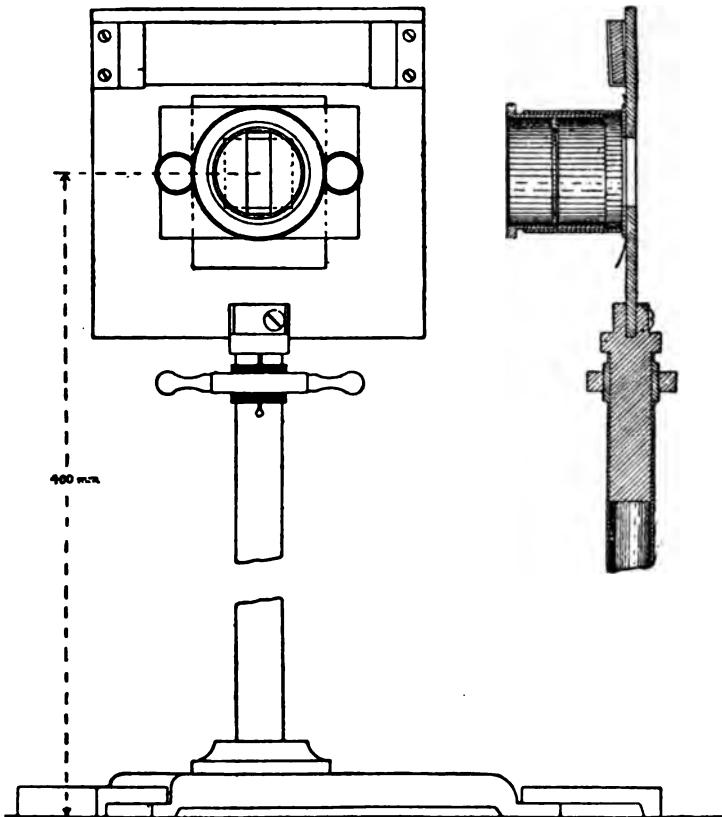


FIG. 18.—PHOTOPED (TABLE PHOTOMETER.)

7) shows that the lamp, burner, and the surface of the paper form a triangle, to the perpendicular of which the photoped, if correctly placed, is at right angles. A piece

of plate glass is carried in a frame on the burner side of the Photoped plate and tilted forward. If the lamp and the burner are lighted they should, if the Photoped is correctly placed in relation to the imaginary triangle referred to above, each be reflected centrally on this piece of plate-glass. The upper part of the Photoped is made adjustable on the pillar, so that this adjustment can be made until the central reflection is obtained.

122. THE 10-CANDLE LAMP.—This is Mr. Harcourt's 10-candle Pentane Standard lamp, the genesis of which is described in the chapter on Standards of Light. In it air is saturated in a carburetter with Pentane vapour, and falls by gravity to a steatite burner of the Argand type. The flame is drawn into definite form by the long brass tube above the burner, which takes the place of a chimney, and the part of the flame which is used as a Standard is not surrounded by a glass chimney, and thus is free from a great source of error. The interior air supply to the flame is provided in a simple manner. The brass chimney *C* mentioned is surrounded by a larger brass tube *D*, which, being heated by the inner products of chimney, causes an intake of air. It is connected at the top to another brass tube *E*, which serves incidentally as the pillar of the lamp, from which all possible heat is conducted, and from which there is a passage to the centre of the burner. The air within it being thus of greater density than that in the tube *D*, a tendency to fall is created, and thus a current is set up which serves to oxygenate the interior of the flame. The Pentane vapour flows over by gravity, as before explained, and no external means are required to drive it through the burner.

123. The lamp is illustrated in Fig. 19. *A* is the carburetter, which should be two-thirds filled with Pentane, which should not be allowed to fall below one-eighth of an inch from this height. Windows in the front and back of the car-

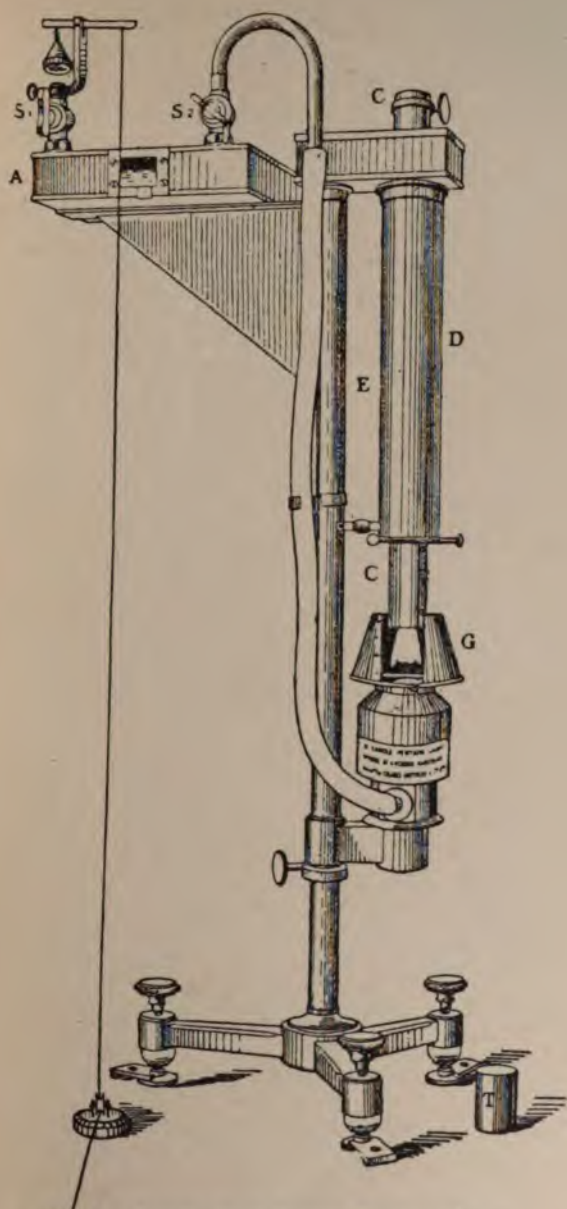


FIG. 19.—HARCOURT 10-CANDLE PENTANE LAMP.

burette enable this height to be observed, as also, whether the lamp is level. The carburette is connected to the burner by means of a piece of black india-rubber tube of good quality. The two cocks S_1 and S_2 serve as inlet for air and outlet for Pentane vapour, respectively, and the height of flame is adjusted by checking this flow of air by either of the cocks. The little cone which is shown depending over S_1 , and which seats upon it, is connected by silk cord to the observer's end of the Photometer, where it can be raised and lowered. By this means the flame can be adjusted without the observer having to turn either of the cocks. This adjusting apparatus is a recent innovation, and is a useful one, because by its use the disturbance of the currents of air round the lamp is avoided.

124. The tube C should be adjusted by releasing the clamp at its upper end and sliding up or down so as to be 47 millimetres above the steatite of the burner when cold. This adjustment is verified by the turned boxwood cylinder which is shown in sketch and marked T . It should also be seen that the tube C and its surrounding tube D are concentric; this adjustment can be made by the three set screws shown at the base of the outer tube. In the base of the chimney tube C is a mica window with a horizontal brass bar across its centre. The tube should be turned round so that no rays of light from this window fall upon the Photoped, but so that it can be conveniently reflected upon the mirror described in par. 120. *The flame is of the right height when the mean of the tips is between the bottom of the mica window and the middle bar.* The height of the top of steatite burner is 353 millimetres above the table. The carburette A should be placed upon the bracket as far from the central column E as is possible, but if the flame after being lighted about a quarter of an hour shows a tendency to become lower, the carburette may be placed

nearer *E*. A conical shade *G* serves to shield the flame, and should be so placed that the whole of the flame can be seen through the opening of Photoped. The lamp should be perfectly vertical; levelling feet are provided, by which it is clamped with clamps to the table. A cover is provided for the top of the burner for use when the lamp is not lighted, so as to prevent an accumulation of dust in the burner or the air passage.

125. *The Pentane*.—It is important that the lamp should be made and used correctly, and it is obvious that it is equally important that the Pentane used in it should be of a standard quality. The following is the text of the procedure which the Gas Referees have arranged with the Gas Companies with regard to Pentane:—

“All Pentane provided by the Gas Companies will be examined and certified by the Gas Referees, and will be sent to the testing places in one-pint cans which have been both sealed and labelled by them; and no Pentane shall be sent to the testing places in one-pint cans which have been thus certified.

“Each of the Gas Companies shall keep upon their premises one or more properly closed vessels capable of containing from fifty to one hundred gallons of Pentane.

“When a supply of Pentane is needed for use in the testing places a number of one-pint metal cans with screw stoppers, of a pattern approved by the Gas Referees (of which a specimen can be seen at their office), shall be provided sufficient to contain the whole quantity required. The size of can to be used is limited to one-pint by the regulations of the Home Office.

“The Gas Referees shall then be informed by letter that this quantity of Pentane awaits their examination, and they will arrange to attend at the premises where the Pentane is stored.

“They will see the cans filled, and will affix a numbered lead seal to each can.

“They will then take away one or more of the sealed cans for examination; the remaining cans must be kept

until the Gas Referees have reported on the quality of the Pentane.

"If the results of their testings are satisfactory, they will prepare as many labels as there are cans of Pentane. Each label will bear the embossed stamp of the Gas Referees, and will be numbered with the number or numbers impressed upon the lead seals on the cans. These labels will then be sent to the company for attachment to the cans.

"No cans of Pentane which the Gas Referees have certified by the attachment of their lead seals and labels are to be supplied to or used by any person or persons other than the Gas Examiners at the several testing places without the written permission of the Gas Referees, and a record must be kept of all cans to which the lead seal has been attached.

"If, however, application should be made to the Gas Referees by the London County Council, the Corporation of London, or any of the Metropolitan Gas Companies, to examine and certify Pentane in reasonable quantities for non-official testings, they will be willing to do so.

"If the Gas Referees, after examination, find that the sample of Pentane taken from any vessel does not satisfy the requirements of their notification, they will inform the Gas Company of the fact; and in such case the lead seals are to be cut off from the other cans filled from the same vessel, and returned to the Gas Referees.

"The Gas Companies will send the certified cans of Pentane to the testing places in their several districts. The Gas Examiner at any testing place will take the presence of the Gas Referees' lead seal and label, bearing identical numbers, upon any can, as evidence that the Pentane which it contains has been certified, and no Pentane shall be used in any testing that has not been so certified."

126. The following is the description of the mode of preparation and testing of what will be hereafter referred to as Standard Pentane:—

PREPARATION.—Light American petroleum, such as is known as gasoline and used for making air-gas, is to be further rectified by three distillations, at 55° C., 50°, and

45° in succession. The distillate at 45° is to be shaken up from time to time during two periods of not less than three hours each with one-tenth its bulk of (1) strong sulphuric acid, (2) solution of caustic soda. After these treatments it is to be again distilled, and that portion is to be collected for use which comes over between the temperatures of 25° and 40°. It will consist chiefly of Pentane, together with small quantities of lower and higher homologues whose presence does not affect the light of the lamp.

TESTING.—The density of the liquid Pentane at 15° C. should not be less than 0.6235 nor more than 0.626 as compared with that of water of maximum density. The density of the Pentane when gaseous, as compared with that of hydrogen at the same temperature and under the same pressure, may be taken. This is done most readily and exactly by Gay-Lussac's method, under a pressure of about half an atmosphere and at temperatures between 25° and 35°. The density of gaseous Pentane should lie between 36 and 38.

Any admixture with Pentane of hydrocarbons belonging to other groups and having a higher photogenic value, such as benzene or amylene, must be avoided. Their presence may be detected by the following test: Bring into a stoppered 4-ounce bottle of white glass 10 cubic centimetres of nitric acid, specific gravity 1.32 (made by diluting pure nitric acid with half its bulk of water); add 1 cubic centimetre of a dilute solution of potassium permanganate, containing 0.1 gramme of permanganate in 200 cubic centimetres. Pour into the bottle 50 cubic centimetres of the sample of Pentane, and shake strongly during five successive periods of 20 seconds. If no hydrocarbons other than paraffins are present, the pink colour, though somewhat paler, will still be distinct; if there is an admixture of as much as one-half per cent. of amylene or benzene, the colour will have disappeared.

127. The Referees' jurisdiction does not extend beyond the three Metropolitan Companies, but it is nevertheless necessary that Standard Pentane should be used with the Pentane Lamp in districts outside of London. The writer went into the question of Pentane supply very closely when the

10-candle lamp was first made the Standard, and, as a result, the manufacture was arranged in conjunction with Messrs. Alex Wright & Co., Ltd., on the basis of a large and constant supply, as opposed to an experimental scale. The market price of Pentane has thus been very materially reduced, owing to the large quantities sent out, and it is now possible to obtain it cheaply and with the certainty of its standing the test laid down by the Referees, as set forth in par. 126. There is an important point, not a technical one certainly, but one that it is necessary to refer to, and that is the cost of carriage. The Railway Companies impose a minimum rate of 5 shillings, which covers the weight of a large quantity, but which cannot be reduced even if only a half pint is sent. It is obvious, therefore, that it is better to purchase in, say, 5-gallon or larger lots, as the carriage then only becomes a small item, whereas 5 shillings added to the cost of a small quantity makes a material difference in the price per gallon. Pentane should be carefully kept in proper cans, or, better still, in small tanks—in a cool place, so as to avoid all possibility of loss by evaporation. It will be found advisable to verify the bulk in the laboratory in the manner described in par. 126, and only to take, say, a pint as it is required into the testing-room, either in a screw-stoppered tin or a small glass-stoppered bottle.

128. THE BURNER.—This is the Standard London Argand burner described in par. 13. If any other burner is prescribed it can be used. The Argand burner is mounted on a tripod stand with flat feet, and secured to the table in a similar manner to the Photoped already described. *The height of the top of steatite burner is 353 millimetres above the table.*

129. THE MEASURING RODS.—The positions of the Photoped, Standard Lamp, and burner having been de-

scribed, it now remains to consider the means by which these distances can be verified. These are two light mahogany rods, each fitted with a turned and shouldered plug transversely to its length, and of such a size as to fit into the steatite rings of the lamp and Argand burner. The measuring rods are terminated with pieces of ivory rounded at the point, and measure from the extremity of these ivory tips to the centre of the boxwood plugs exactly 1000 and 1265 millimetres, respectively. The rods are balanced so that the plugs can be inserted carefully in the steatites, and should when gently moved on these centres just touch, at their ivory ends, the centre of the Photoped plate. The distance from the lamp to the burner is verified by a similar rod, but with two plugs attached, the distance between the centres of which is 522 millimetres. The relative positions of the Photoped, lamp, and burner must be adjusted until the measuring rods show the distances to be correct. The height of the steatite burners from the table is adjusted by the three-sided rectangular height gauge provided, the steatites in each case allowing the limbs of this to touch the table while the crosspiece is resting on their surface. It is important that the lamp, burner pillar, and Photoped be perfectly vertical.

130. DISTANCES FOR GASES OTHER THAN 16-CANDLE-POWER.—It will be seen from above paragraph that the distances of the 10-candle standard and the gas burner are fixed on the assumption of the comparison of gas of 16-candle-power (given 5-feet rate). If it is desired to test gas of a different reputed quality, say, 14, 15, 16, 17, 18, 19, 20 candle-power (on the same rate basis) the burner must be placed at a proportionate distance from the Photoped. The distances, with the lamp in the same position, namely, 1000 millimetres, are:—

14	candle	gas	(5 feet per hour)	=	1,183	millimetres.
15	"	"	"	"	=	1,224.5
16	"	"	"	"	=	1,265
17	"	"	"	"	=	1,304
18	"	"	"	"	=	1,341.5
19	"	"	"	"	=	1,378.5
20	"	"	"	"	=	1,414

A special burner pillar, called the Birmingham pillar (it be-

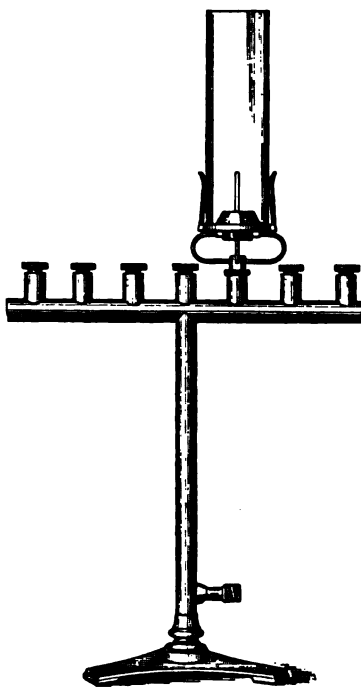


FIG. 20.—SPECIAL PILLAR FOR VARYING QUALITIES OF GAS.

ing first made by the writer for use in Birmingham) is arranged with sockets at the proper distances, and movable plugs, any of which can be replaced by a hollow plug carrying the Argand burner—which can thus be placed at any of the desired distances. (See Fig. 20.) The measur-

ing rod is also made adjustable, the boxwood plug sliding, and capable of being clamped at any of the distances which are marked in candle-powers upon the rod.

131. *The Quadrant, or Regulating Tap* (Fig. 21),

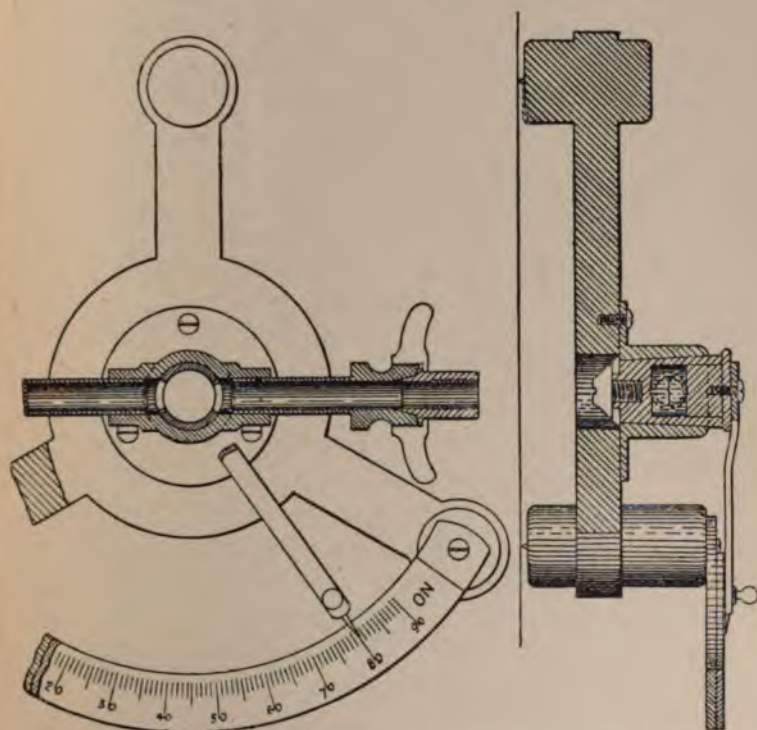


FIG. 21.—REGULATING COCK (TABLE PHOTOMETER).

forms an essential part of this Photometer. It is arranged, as shown on the plan, so as to regulate gas between outlet of governor and the burner, and has a quadrant extending over 90 degrees, and a pointer attached to the plug, indicating upon this. The arc is marked in degrees from 0° to 90° , and the tap is fully off at 0° and practically fully on

at 90° . The tap is constructed so as to be "slow-opening," and consists of a large conical plug arranged to work easily in a barrel which screws down to the foot or stand of the cock from the top. By this means the plug can be taken out without disconnecting the tap, and owing to the small way through the plug it may sometimes be necessary to do this in order to remove condensed moisture. The way in the plug consists of a small hole on each side of it, passing about 4 feet per hour at about $\frac{6}{10}$ th pressure, and in addition there are narrow saw-cuts on opposite sides of the two holes, arranged to give an additional 2 feet per hour. *In this manner the passage of the gas increases gradually, and this has the effect of making the graduated arc an "open" scale. A reference to par. 142 will show the necessity of this.* When testing with a Table Photometer it should be seen that the tap is nicely made, as it plays an important part in the tests, and it must, therefore, do its work well, or it is worse than useless.

132. *The Experimental Meter.*—This is a meter of the same capacity and description as that described in par. 28, but it has no index. It has simply a pointer sleeved direct on the spindle of the measuring drum, which is of $\frac{1}{8}$ th cubic foot capacity. The pointer thus indicates $\frac{1}{8}$ th cubic foot per revolution, the dial being divided into 100 equal parts, and protected by a glass front. The meter is preferably made in incorrodible porcelain, and is finished dull black; it is provided at its inlet with a carefully-made three-way cock for use with $\frac{1}{2}$ cubic foot bottle. (See par. 138 *et. seq.*)

133. *The Minute Clock.*—This is a clock as described in par. 38. It must be capable of being read to $\frac{1}{2}$ a second, and the case is finished in dull black. The clock must be kept in good adjustment.

134.—*The Experimental Governor.*—This is a sensitive

balance governor similar to that described in par. 39. The tank and bell are preferably made in incorrodible porcelain finished in dull black. A black screen $8\frac{1}{2}$ inches high and 6 inches wide is placed near the tank of governor (as shown in Fig. 17) to prevent heat of the Argand burner from warming the water in the tank.

135. *Pressure.*—It will be observed that no pressure gauge is specified. The Referees do not consider it necessary, nor has it the utility that a gauge has on a Letheby-Bunsen Photometer, where by its means a speedy adjustment can be made to the 5-root rate. The pressure to inlet of the Photometer should be regulated by a service governor, *and the balance governor so loaded as to be at its most sensitive point*, so as to respond readily to the movement of the regulating tap. Some little experience will be found requisite in order to obtain this result in a new Photometer, and the necessity for the careful adjustment of the Experimental Governor will be apparent after a few tests have been made.

136. *The Connecting Pipes.*—They are block-tin pipe of good quality and half-inch outside diameter. Only three pipes are required, viz., from governed service to inlet of meter, from outlet of meter to inlet of Experimental Governor, from outlet of governor to burner pillar. The latter pipe is intercepted by the quadrant tap (131); the connections are made by $\frac{3}{8}$ -inch unions. The Referees make no provision for syphon taps; it will be found advisable, with all due deference to them, however, to drop tubes through the table at one or two points, finishing with drip cocks for draining condensed moisture.

137. *The Aerorthometer* has been described in par. 58. The Tabular Number (from barometer and gas temperature, see Table D in Appendix) can be used instead of the Aerorthometer number.

138. *The One-Twelfth Cubic Foot Measure.*—This mea-

sure, to which reference was made in par. 37, consists of a glass vessel as illustrated in Fig. 22, the end tubes being 40 millimetres diameter outside, reducing to 20 millimetres diameter at their extremity. The end tubes are each marked with a line in such positions that the capacity of that portion

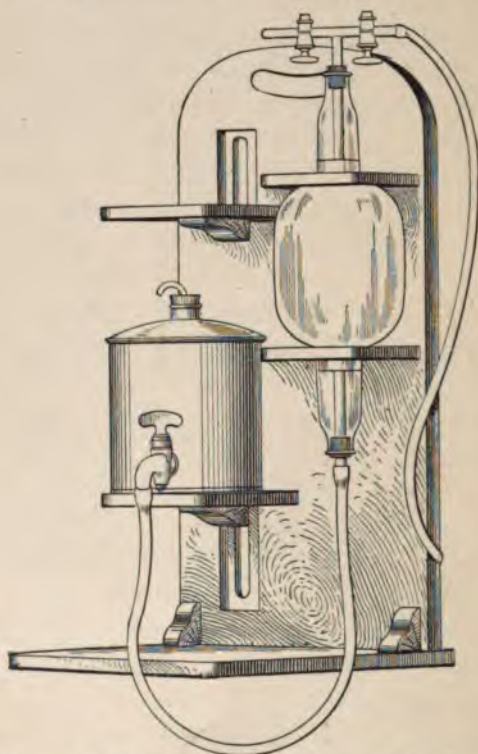


FIG. 22.—ONE-TWELFTH CUBIC FOOT MEASURE.

of the vessel included between these marks is exactly one-twelfth of a cubic foot at ordinary temperature. No correction is needed for the expansion of the glass, but the water used should approximate to the temperature of the gas in the experimental meter, otherwise an error due to the altera-

tion of volume of the gas itself would ensue. The bottle is mounted between the shelves of stand as shown. The ends are closed by rubber corks with bores of sufficient size to take, water-tight and gas-tight, two glass tubes of 8 millimetres outside diameter, the lower tube being plain, while the upper one terminates in a T, with two glass cocks of sufficient bore. The lower tube is connected water-tight to the metal cock of a tinned copper aspirator of about $\frac{1}{10}$ th cubic foot capacity, and fitted with a rubber cork with bent glass vent tube as shown. The aspirator is placed on the two remaining shelves of stand, both of which are adjustable.

139. *To Adjust the Bottle.*—Water is placed in the aspirator and the metal tap opened, as is also one of the glass taps on T-piece. The aspirator is placed on the lower shelf, which is adjusted until the water, which has then access to the bottle, is level with the mark on the *lower* end of the bottle. The aspirator is then placed on the upper shelf and the water rises in the bottle, the shelf being adjusted until the water is level with the mark on the *upper* end of the bottle. This adjustment being made, it will be apparent that the transfer of the aspirator from the upper to the lower shelf, or *vice versa*, either draws in or expels $\frac{1}{12}$ th of a cubic foot of air or gas. Since the two glass tubes which pass through the rubber corks are adjusted so that their ends are level with the marks on the bottle, a slight error in the water-levels would only affect the capacity as regards a small portion of the internal capacity of a tube 8 millimetres in outside diameter. Thus a variation of an inch in the level at which the water stands has no appreciable effect on the reading of the meter.

140. *To Make a Test.*—The tap at the back of the experimental meter has three ways, viz., from service to meter, from service to flexible tube connection

(which is connected by rubber to one end of the glass T of $\frac{1}{12}$ th cubic foot measure), and from $\frac{1}{12}$ th cubic foot measure to meter. The plug is so shaped as to indicate in which direction the tap is open. In order to prove the meter, connect the three-way tap to the glass T, place the aspirator on the lower shelf, seeing that the second tap on glass T is closed, and thus fill the bottle with gas. If the water does not rest level with the lower mark make the necessary adjustment of the lower shelf of aspirator stand, as explained above. Next turn off aspirator tap, *note the position of pointer of meter*, turn the three-way tap *half way* towards the position which leads from the bottle to the meter, and momentarily open the tap on the free branch of the glass T so as to bring the gas in the bottle to atmospheric pressure. Next put aspirator on upper shelf (previously adjusted for level), open the regulating or quadrant tap (par. 131), turn the three-way tap *so as to open the way from the bottle to the meter*, and turn on the tap of the aspirator. The water then flows into the bottle, sending $\frac{1}{12}$ th of a cubic foot of gas through the meter. *The pointer should rest at the position it started from.* The operation is repeated three times. If the hand of meter has travelled in the three tests one division beyond the point from which it started, the meter is fast, and water must be removed; if the travel of the hand is as much as one division short of the starting point, the meter is slow, and water must be added. The test is repeated until the meter is correct within these limits. The water in the $\frac{1}{12}$ th cubic foot measure must not vary from the temperature of the gas in the meter by more than two degrees. A chemical thermometer is provided for ascertaining the temperature of the water. The way in the various taps of the $\frac{1}{12}$ th cubic foot measure should be sufficiently large that the bottle can be emptied of one charge of gas in a little more than a minute.



The form of stand illustrated in Fig. 22 is devised by Mr. Simmance, and is permitted by the Gas Referees to be used in London Testing Stations. It has obvious advantages over the two stands originated by the Referees and illustrated in their notification.

To Test with the Table Photometer.

141. *To Insure Accurate Results*—the Photometer should be tested for soundness by replacing the burner with a blank cap, putting on full pressure and observing that the meter hand is stationary for several minutes. Use the $\frac{1}{12}$ th cubic foot measure and the distance gauges at least weekly. The minute clock, barometer, meter-thermometer, should be verified periodically, while the Aerorthometer (if used) should be verified at least every fourteen days. Only use Standard Pentane. Never fill the saturator while the lamp is alight. Empty the saturator or carburetter once a month; at other times keep it two-thirds full. Verify the height of chimney tube of Pentane lamp above the steatite. It should be 47 millimetres, and central. See that the paper in the Photoped is clean. The paper should be white, unglazed, of fine grain, and free from water-marks. It should be as translucent as possible, but at the same time must be sufficiently opaque to prevent any difficulty in reading the relative brightness of the two portions of illuminated surface. Use a clean chimney on the Argand burner before each testing. Turn all gas lights other than the one on the Photometer out, or very low, at least ten minutes before readings are taken, and let them remain so until the time indication is secured. No moving about the room should be permitted for a few minutes before each reading, and if any other person is present the operator should note the fact in his report. No test

should be made unless the gas flame is perfectly steady; and should it appear impossible to get the flame into absolute rest, the examiner (who should sit at the Photoped end of the Photometer after lighting the burners, etc.) should report the fact.

142. *To Make a Test.*—The gas under examination and the Pentane lamp should burn for about fifteen minutes, at about their usual height, previous to the test. The water in the meters should be thoroughly saturated with gas at the temperature at which the test is made. Adjust the height of the Pentane Standard (par. 123). Slowly turn the regulating tap till the gas flame gives *less* light on the



FIG. 23.
THE PHOTOPED PAPER.
(Gas less than
Standard.)



FIG. 24.
THE PHOTOPED PAPER.
(Gas equal to
Standard.)



FIG. 25.
THE PHOTOPED PAPER.
(Gas greater than
Standard.)

Photoped than the Pentane lamp, Fig. 23, and turn on gradually until the square is equally illuminated, Fig. 24. (For the proper adjustment of the parallel bars of light see par. 121.) *Read the position of pointer on quadrant and note.* Next turn the regulating tap till the gas flame gives *more* light on the Photoped than the Pentane lamp, Fig. 25, and turn on gradually until the square is again equally illuminated, Fig. 24. *Read the position of pointer on quadrant and note.* Repeat the double readings, and set the pointer



at the mean of the four positions. Verify the reading on the Photoped, and then ascertain the actual time in seconds taken by two revolutions of the meter-hand with the pointer set in this position.

143. Take the Tabular number and the Aerorthometer number and work out the illuminating power by both of the following formulæ:—

$$\text{Illuminating power} = \frac{\text{aeror. reading} \times \text{time in seconds}}{7.5 \text{ (constant for 16 candles)}}$$

$$\text{Illuminating power} = \frac{\text{time in seconds}}{\text{tabular number} \times 7.5 \text{ (constant for 16 candles)}}$$

NOTE.—These formulæ are for tests when the burner is fixed at the 16-candle distance. The Referees have prepared a table which gives the corrected results in cross column (see Table H in Appendix). When the tables are used and the figures of the test come between those given in the tables, the result is found by taking proportional difference between the two nearest figures in the cross column. The constant for tests with the burner at other distances (replacing the figure 7.5 given above) are, as under

14 candle.....	8.5714
15 “	8.0
17 “	7.0588
18 “	6.6
19 “	6.3156
20 “	6.0

The writer has prepared tables for 14, 15, 17, 18, 19, and 20 candle gas (similar to the Referees' 16-candle table), which will be found in the Appendix, and numbered Tables H_1 , H_2 , H_3 , H_4 , H_5 , and H_6 , respectively.

The Photometer Room.

144. In the instructions laid down for the proper conduct of photometrical experiments the following points have been insisted upon, viz.:—

1. The accuracy of the instruments as measures.
2. The proper condition of the instrument of comparison.
3. The observation of the atmospheric pressure.
4. The observation of the temperature of the gas.
5. The reduction of the volume of gas measured to its volume under normal conditions.
6. The regulation of the temperature of the room.
7. The presence of proper conditions in the testing room, and the non-disturbance of same by the observer.

The above will be generally admitted to be sound rules, resting upon a basis of common-sense, and it will at once be seen that numbers 1 and 2 are easily capable of control.

145. *Atmospheric Pressure.*—The effect of varying atmospheric pressure (3) is more complex, and it cannot be controlled. A difference in the barometer affects not only the volume of gas measured, but probably the result of the combustion of coal or other gas, of candles, and of Pentane vapour. If, therefore, these illuminants are affected photometrically to a different extent, we have an ever-present and varying error which cannot be eliminated. We do know that in a Pentane flame like Mr. Harcourt's 1-candle burner the height of a flame giving the same light varies inversely with the atmospheric pressure. The writer is not aware that it is known what effect a change in atmospheric pressure has upon an Argand Pentane flame, or whether it is comparable with the change (if any) brought about by the same cause in the illuminating power of a more complex hydrocarbon flame, such as coal gas. The Board of Trade Committee on Photometric Standards stated in their report in 1895 that it was probable that the value of a Pentane Argand flame was not affected by such changes in atmospheric pressure as commonly occur. All the experimentalist can do, therefore, is to make a correction for atmospheric pressure upon the volume of gas consumed (5).

146. *Temperature.*—The effect of varying temperature

is twofold. It alters the volume of the gas consumed (4), and this can be and is corrected for. It should, however, even for this purpose, be kept within as narrow a range as possible, as it is open to question whether extreme corrections of the tabular number give an accurate net result to the gas. It also has a varying effect (coupled with humidity) upon the light yielded by a Pentane gas flame and an Argand gas flame. Some experimentalists hold that the effect on these flames is not a parallel one, while others think differently. It has been held, however, by the Committee referred to above, which included some of the most experienced and competent experimentalists, that *if the temperature is kept within narrow limits* the error caused is so confined as not to be appreciable, and that, given the narrow limits, it can be disregarded. It is thus plain that it is advisable and—if reliability and accuracy of results are desired—imperative *that the temperature should be controlled and kept within limits in every Photometer room* (6). Now the use of gas for heating (and it would always be available in a room where gas is tested) facilitates greatly the problem of efficiently controlling the temperature of the testing room, and an apparatus for thermostatically regulating the heat in a room is described and illustrated below. *If the need for this heat regulation is recognised, and it is difficult to see how it can be combated, it follows that reliable tests can only be made in a room fitted up for the purpose, and with this and the other provisions hereafter referred to carried out.*

147. *The Thermostat.*—An instrument has been arranged by Mr. Simmance and the writer by means of which the gas supply to a stove, furnace, or other heating apparatus is automatically increased or decreased, proportionately to the decrease or increase of the temperature of the room. If a reference is made to this particular instrument

it is because the writer knows of no other form which is efficient, easily applied, and not liable to get out of order. The illustration shows the instrument complete. *A* is a wooden case with a plate-glass front open a little at the top and bottom, but so arranged that when the top of case is fastened by the padlock no part of the apparatus can be got at with-

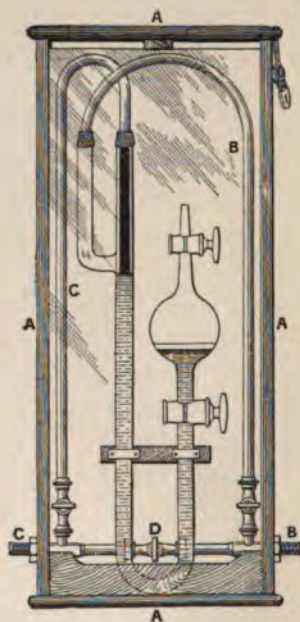


FIG. 25.—THERMOSTAT.

out breaking the glass. *BB* is the inlet gas supply, *B* being a $\frac{1}{2}$ -inch barrel union for connection to the service of stove or furnace, *which must be governed*, while *B* is a piece of tin pipe bent so as to join with rubber to the inlet of thermostat proper. *CC* is the outlet gas supply, *C* being a $\frac{1}{2}$ -inch barrel union for connection to the stove or furnace. *B* and *C* are joined by a piece of pipe, in the centre of which is a cock *D*.

Through this pipe gas can pass without being controlled by the thermostat, and by means of the cock *D* a permanent pilot on the stove, which is necessary, can be adjusted. In the branch of the thermostat, which is made of glass and which connects to *C*, is fitted a piece of vulcanised fibre tube, slotted a short way up from its lower end. Mercury is placed in the thermostat through the cock on top of the bulb, and in the bulb on top of the mercury is placed a little Pentane and the glass cock is closed. Now the gas has to pass from *B* to *C* through the Y-tube, and in order to do this it must pass through the slot suspended in one of the limbs.

148. The action of the thermostat is simple. The bulb is filled with saturated Pentane vapour, and Pentane, being very sensitive to changes of temperature (passing from the liquid to the gaseous state very readily and *vice versa*) when the temperature of the room rises, a pressure is put upon the mercury, causing it to shut a portion of the slot in the vulcanised tube, and so automatically lessen the gasway; when the temperature falls the reverse action takes place and the gasway is again increased. In this manner an equilibrium is maintained. The thermostat requires adjustment when it is first fitted, and can be arranged to regulate the temperature at any reasonable degree. No attempt should be made to adjust the apparatus until the mercury has been kept at the temperature which it is desired to maintain in the room for a day at least.

149. *Proper Conditions in Testing Room.*—Dealing now with point No. 7 in the list of essentials laid down in par. 144, we have first to define what is meant by “conditions.” By “conditions” is meant any outside influence or influences due to situation, construction, or ventilation of a room which can affect the accuracy of a test, firstly, by influence upon the Standard of light; secondly, by influence upon the Argand burner. The whole subject is at present considered debat-

able ground, and it involves many conflicting interests; in fact, the question was one round which the recent fight over the admissibility of a legalised portable Photometer centred. The writer thinks, however, that the view *that Standard "conditions" are as necessary to accurate photometric results as is an accurate gas meter*, is so indisputable and incontrovertible that the matter deserves to be removed from the arena of dispute and added to the list of acknowledged facts, and for that reason it figures in the list of essentials to accuracy detailed in par. 144. It must be admitted that the point is one of those intangible ones which are likely to and therefore have escaped notice to a great extent; but there certainly seems no reason why the Legislature, when it defines and certifies a Standard Photometer (which it does through the Board of Trade), should not at the same time examine and certify every Standard Photometer Room, which should be devised in such a way as to always secure Standard conditions, however varying the surroundings.

150. A Standard Photometer Room with unvarying "conditions" is certainly possible of construction, and it does appear that the efforts of gas manufacturers should be directed to this end, if only from a purely selfish point of view. It has never been advanced (to the writer's knowledge) that, given accuracy of instruments and freedom from bias of the examiner, it is possible to *appreciate* the apparent photometrical value of the gas. It is equally certain, on the other hand, that it is in the experience of most gas managers that there have been occasions when the value of the gas has been *depreciated* in a photometrical test, and without any apparent cause. It is this uncertainty which should be done away with, and the gas tested under conditions which ensure its proper illuminating value being observed. There is one "condition" which is a variable one, and which does affect the power of light yielded by Pentane gas and

other burners. That "condition" is humidity, and, as seen from par. 178, its effect under extreme circumstances is very marked. It is, therefore, both desirable (and possible to a great extent) to keep under control the hygrometric conditions of a testing room, if accurate results are desired.

It is proposed to touch upon some further influences which tend to depreciate the result of photometrical tests, and to define and describe means of rendering such tests independent of outside conditions.

151. *The sensitiveness of the Argand burner* is the most frequent cause of inexplicable results. It must be remembered that the Argand burner (which is chosen because the light given by it responds so readily to changes in the quality of the gas) is made in all its principal dimensions, viz., its gasways, its point of ignition pressure, its inner and outer airways, and its chimney, to an extreme accuracy. (See par. 13.) It follows, therefore, and is a fact, that if any of these dimensions are varied the developing efficiency of the burner is reduced, and it goes without saying that the *burner is adopted as the Standard on the basis of a certain fixed developing efficiency*. The burner is now used in open Photometers, as defined by the Standards Department, on Table Photometers, and in connection with Portable Photometers, and it is therefore necessary that, whenever and however used, some provision should be made by means of which its proper efficiency can be developed with certainty. If a reliable closed Photometer, independent of the conditions of the room, could be made (and experiments are now being made in this direction), this would solve the difficulty; but closed Photometers (as the term is now understood), the Evans, for instance, have been shown by years of experience to be utterly unreliable, and not independent of outside conditions. Therefore, as a means to the very desirable end, viz., consistent and accurate tests, they can be

put on one side, and it is the room that must at present be looked to as a means of controlling the efficiency of the burner.

152. It is the supply of air to the Argand burner which is so important, as it is a matter of common knowledge that the supply of air to an Argand or other burner (given a constant quality of gas) absolutely governs its efficiency. As an instance of this it will be remembered that with the Standard Argand burner, a different-sized chimney (to ensure a different amount of air feeding the burner) is used with 14-candle or 16-candle gas. The Gas Referees, in a report made by them to the Board of Trade in 1871, stated:—

“Not to take into careful account the influence of the burners when testing the illuminating power of gas, is as great an oversight as if, in weighing, one were to make no examination of the balances. . . . *The proper regulation of the supply of air to the flame of an Argand burner is the chief secret of developing a maximum amount of light from gas.* . . . The stream of burning gas from the burner rising through the (we shall say) quiescent atmosphere of the room, draws in the air upon itself, just as a rapid stream passing through a pool or lake disturbs the stillness of the pool, and draws in upon itself in eddies the surrounding waters. . . . The important bearing which the above statements have upon any question connected with gas illumination is manifest at a glance. They illustrate the chief conditions which affect the illuminating power of gas; *they show how great may be the variations of that illuminating power in which the gas is consumed, even in the same burner.*”

153. Some experiments in which the writer took part were recently made, in order to investigate carefully the effect of varying conditions on photometrical results. A long series of tests was made, in which stored gas was used, the gas being drawn off the main and placed in a large experimental gas-holder. A Table Photometer was placed in the Photometer room, which was properly constructed.

but arranged for experimental purposes in such a way that the areas and direction of the air inlets and air outlets could be altered so as to draw through the room varying quantities of air, and at different speeds. It was found that with every precaution taken, and with the results compared by several experimentalists, a variation of over one candle was produced in the corrected readings of illuminating power of the stored gas, and that the variations could be produced in response to certain changes in the air supply to the room. Such variations were only to be expected. An acceleration of the upward current of air through the Argand burner by means of increased ventilation has precisely the same effect as would an alteration in the length of the Argand chimney. Figs. 27 and 28 are respectively a plan of the arrangement of Photometers used, and a chart of results.

154. Thus, it was conclusively proved that the Standard London Argand burner only yields its maximum duty, under conditions which permit its peculiar dimensions of construction to exercise their influence over combustion when free from interference by extraneous circumstances, and that this condition remains, whatever the Standard of light used.

155. We find ourselves, then, in this position, that we know the air supply to the burner governs to a large extent the reliability of our photometrical tests, and that in the conditions under which we test, the supply of air to the burner is absolutely governed by the ventilating conditions of the room; or, in other words, if the conditions alter, the efficiency of the burner is liable to alter. These points are disregarded in most Photometer rooms, and the obvious remedy for this state of things is to obtain a means of governing the air supply. The following are the general principles which should be followed to gain this end, from which it will be seen that in practically all cases a good Photometer room is quite within a gas manager's reach.

156. Size is of secondary importance so long as air is supplied in sufficient quantities in a steady stream and rea-

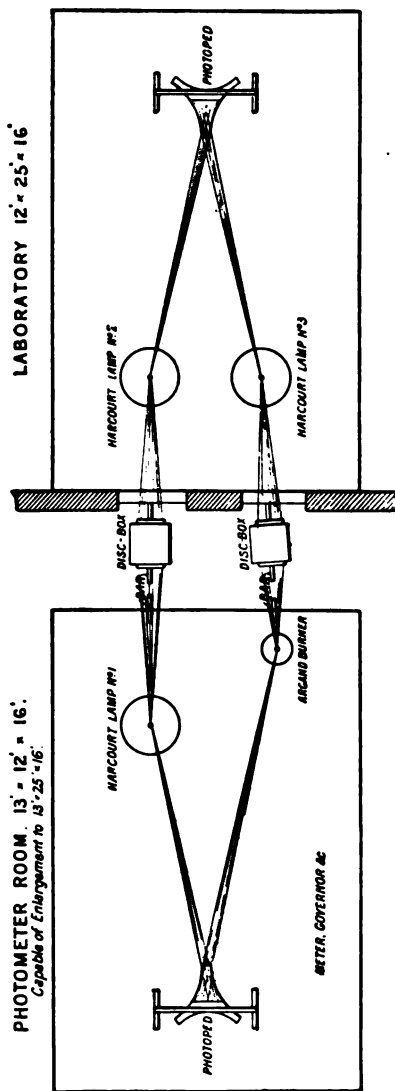


FIG. 27.—PLAN OF EXPERIMENTS AS TO VARIABILITY OF ARGAND BURNER.

sonably dry, so divided in its conduits that its initial velocity is subdivided by many openings, aggregating several times the area of the primary inlet and thus susceptible of easy warming and control as to suspended moisture or humidity, whilst preventing draught. These points are more readily

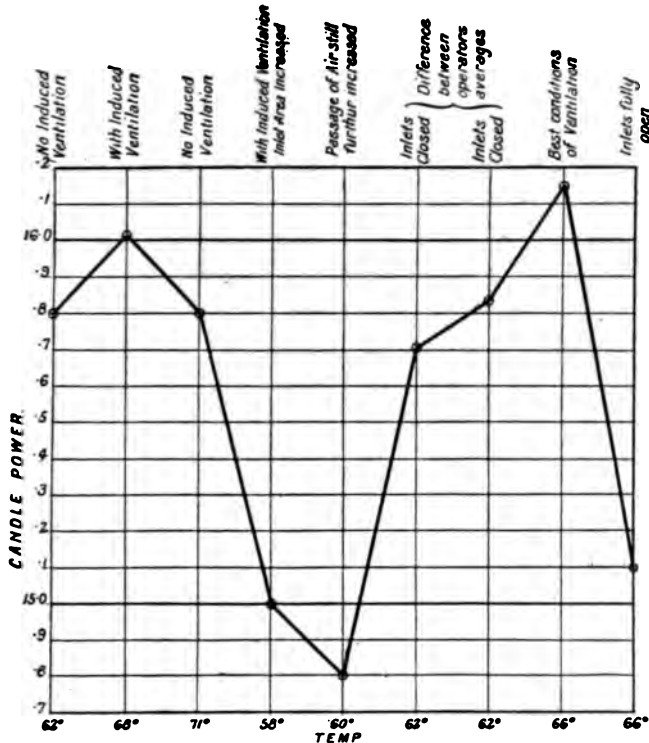


FIG. 28.—CHART SHEWING VARIABILITY OF ARGAND BURNER.

attained in large rooms than in small, hence the desirability to use the former if possible. The air currents must always be in one direction, move at one speed, and issue by one outlet. Any hesitancy or impeding by a partial back-draught, or increase of speed through extra aspiration, will upset the

balance to be aimed at, with deleterious effects on the Argand burner results. With properly arranged ventilating apparatus (what is good enough for a living-room is not so for a Photometer room), and an efficient heating system controlled by a sensitive thermostat (see par. 147), it is possible to so equilibrate the air supply that the very best result is obtainable on the Photometer, and this irrespective of actual size of room. It will in all cases be found necessary that when the ventilating apparatus is fixed, experiments and adjustment will have to be made until the *air always, whatever the condition of the wind or outside temperature*, is drawn round the burner in the tranquil, steady stream described by the Referees, and proved by experience to be a necessity to correct results.

157. Summary of points to be observed in Photometer room (dark or otherwise) :

- (a) Take in the air through distributed inlets.
- (b) Warm the entering air in cold weather, and cool the entering air in warm weather.
- (c) Ensure that the entering air is never checked by a back draught.
- (d) Remove the suspended moisture or humidity from the entering air.
- (e) Automatically regulate the temperature of the room.
- (f) Exhaust without draughts the foul air and products.
- (g) Ensure that the issuing air is never checked by a back draught.
- (h) Ensure that the speed of the air through the room (when once fixed after experiment) never varies.
- (i) An aggregate of these perfectly obtainable points will render a testing-room independent of all outside conditions.
- (j) It goes without saying that the room selected must be free from vibration. A basement is, generally speaking, unsuitable.

158. The form that the ventilating and heating apparatus should take can (in the absence of any Government regulation, such as practically obtains in Germany) be varied to suit the constructions of different rooms, but its effect must in all cases be the same. A good example of a properly regulated Photometer room, and one that might well serve as a model, is the Testing Station at Sheep Street, Birmingham, which was fitted up under Mr. Chas. Hunt's direction, and the provision of which solved one of the most apparently inexplicable of photometrical puzzles. *It may be taken as an axiom that, with Photometers as at present constructed, the Photometer room is a part of the Photometer.*

Reduction in Illuminating Power of Gas.

159. A movement has recently been set on foot to bring about the reduction of the illuminating power of gas. It has for its basis the premises

1. That 14-candle (say) gas can be made from ordinary gas coals without enrichment.
2. That gas thus made can be sold much more cheaply than gas, to produce the highest few candles of which a large expenditure is necessary.
3. That low-candle power gas can be made without enrichment, which for purposes of heating, cooking and lighting by incandescence is not appreciably inferior to 16 or 17-candle gas.

160. Mr. Geo. Livesey of the South Metropolitan Gas Co. has succeeded in gaining the necessary Parliamentary powers for his company, and the reduction in illuminating power and price has already taken place. The success of the movement depends to a large extent upon the popularisation and cheapness of incandescent burners and mantles,

and also upon the prompt appreciation by makers of incandescent burners, and of cooking and heating stoves, of the alterations necessary in their manufactures to enable the power of lower quality gases to be utilised to the fullest extent. An exhibition at the Crystal Palace has been organised for the purpose of publicly demonstrating the efficiency of the low power gas, and seeing that the movement will no doubt in many places be beneficial to producers of gas one may anticipate its spread.

161. The question of the relative efficiency as to heating and lighting of low and high power gases will naturally occur to the reader, and it may be he will hope to find records of tests in this direction. The writer has purposely refrained from giving any of these records, because, as pointed out in the chapter on Calorimetry, he considers such results to be purely local and to vary with different methods of carbonisation, condensation, etc. (See chapter on Calorimetry.)

[NOTE.—Pars. 162 to 169 are left blank to facilitate additions in any future edition.]

CHAPTER III.

STANDARDS OF LIGHT.

170. At the present time there are two Legal Standards of light in use in this country, viz., Standard Sperm Candles and Harcourt's Ten-Candle Pentane Lamp.

171. STANDARD SPERM CANDLE.—This is the standard in general use in Great Britain, and is specified for use by the Gas Works Clauses Amendment Act, 1871, Schedule A, Parts I and II. (See pars. 10 and 15.) Notes on the use of this will be found elsewhere in this volume, and it will, therefore, suffice to state that the candles are to be of spermaceti (with beeswax), weighing 6 to the pound, and are to consume 120 grains per hour each, two being used together for the ten-minute test, consuming normally in that time 40 grains of sperm. It being impossible to ensure the consumption by 2 candles of 40 grains of spermaceti in 10 minutes, it is necessary to make a correction of the illuminating power proportionally to the variation. The Gas Referees insist that the variation of consumption should be limited between 114 and 126 grains per candle per hour—that is, 38 or 42 grains in 10 minutes, or 40 grains between $9\frac{1}{2}$ and $10\frac{1}{2}$ minutes. (See par. 88 and Appendix J.)

Mr. Harcourt's Work on Standards of Light.

172. The Pentane Standards produced successively by Mr. A. Vernon Harcourt, F.R.S., are as follows:—

1. Pentane air-gas made in holder, 1 candle-power, 1877 (par. 179).
2. Pentane air-gas lamp, portable reservoir, 1 candle-power, various forms, 1883-87 (par. 180).
3. Pentane lamp with wick, 1 candle-power, 1887 (par. 183).
4. Pentane lamp with wick, 10 candle-power, 1894 (par. 185).
5. Pentane 10-candle standard, officially adopted, 1898 (par. 186).

All of the above standards have been the subject of much experiment and controversy, and various committees appointed by the British Association, the Board of Trade, and others have reported lengthily and variously as to their merits. The adoption of the Harcourt Ten-Candle Standard (No. 5) for London and elsewhere renders these reports of more or less historical interest, but the writer gives below as concise a *précis* of what might be termed the "Evolution of the Pentane Standard" as is possible, much of the matter being taken from published papers written by Mr. Harcourt.

173. 1. *A Standard Flame*.—"Three conditions need to be fulfilled for the production of a Standard flame. First, the combustible must be of known and definite composition. Secondly, the conditions of burning must be of a simple and definable character. Thirdly, the nature of the combustible and of the conditions of burning must be such that atmospheric changes may produce a minimum of effect upon the light. A fourth condition might be added as highly desirable, namely, that the operator should be able to verify for himself the composition of the combustible he employs. No experimentalist would willingly spend time upon a quantitative operation for the accuracy and significance of which he was dependent upon the care exercised by the workmen of the best maker of candles or refiners of oil."

2. *A Standard Combustible*.—Various qualities of Pentane can and have been manufactured, variations in the conditions and mode of manufacture having been found to yield liquids, termed Pentanes, which, under otherwise equal conditions, give different light values. The Standard combustible which can easily be reproduced and verified is that which is defined by the Gas Referees Notifications of 1899, and is as follows:—

“Preparation.—Light American petroleum, such as is known as gasoline and used for making air-gas, is to be further rectified by three distillations, at 55° C., 50° , and 45° in succession. The distillate at 45° is to be shaken up from time to time during two periods of not less than three hours each with one-tenth its bulk of (1) strong sulphuric acid, (2) solution of caustic soda. After these treatments it is to be again distilled, and that portion is to be collected for use which comes over between the temperatures of 25° and 40° . It will consist chiefly of Pentane, together with small quantities of lower and higher homologues whose presence does not affect the light of the lamp.

“Testing.—The density of the liquid Pentane at 15° should not be less than 0.6235 nor more than 0.626 as compared with water of maximum density. The density of the Pentane when gaseous, as compared with that of hydrogen at the same temperature and under the same pressure, may be taken. This is done most readily and exactly by Gay-Lussac's method under a pressure of about half an atmosphere and at temperatures between 25° and 35° . The density of gaseous Pentane should lie between 36 and 38.

“Any admixture with Pentane of hydrocarbons belonging to other groups and having a higher photogenic value, such as benzene or amylene, must be avoided. Their presence may be detected by the following test: Bring into a stoppered white-glass bottle of from 80 to 100 cubic centimetres capacity, 10 cubic centimetres of nitric acid, specific gravity 1.32 (made by diluting pure nitric acid with half its bulk of water); add a few drops of a dilute solution of potassium permanganate, sufficient to

give to the acid a full and permanent pink colour. Pour into the bottle 50 cubic centimetres of the sample of Pentane, and shake strongly from time to time during five minutes. If no hydrocarbons other than paraffins are present, the pink colour, though somewhat paler, will still be distinct; if there is an admixture of as much as one-half per cent. of amylene or benzene, the colour will have disappeared."

174. The questions of storage and transit will suggest themselves naturally as being of importance. There is no difficulty generally in the way of a gas company keeping a few gallons of Pentane, and it will be found convenient to adopt a modification of the Gas Referees' method, viz., a bulk of certified quality in a sealed tank, to be drawn off and used from, say, pint cans or bottles.

With regard to transit, the Railway Companies have stringent regulations, which are, however, quite practicable and reasonable, and the imposition of a minimum carriage rate renders it more economical to buy a few gallons instead of one or two pints. Finally, the Pentane is now sold so as not to exceed the cost of candles, if care is exercised in its use.

175. *Variations in Height of Flame.*—Of the Harcourt lamps referred to above (par. 172) three are with solid flames, and two have interior air currents, all of which forms are, of course, capable of variation in height either through atmospheric conditions or by design. It may be instructive to examine the influence which varying height in the flame has upon the power of the various standards, and it will be well to include in these remarks Simmance's Pentane Standard of solid flame type and Dibdin's Pentane Standard of the Argand type.

(a) *Solid Flames.*—All of these are sensitive open flames, and, with the exception of Simmance's Standards, more or less difficult to keep constant. It has been found with Stand-

ards Nos. 1 and 2 that a considerable difference is observed in the result if the heights vary, and that if the height of the flame is set by cut-off screen, or merely by a platinum wire height-gauge, the results are different. It appears to be the correct way to use a cut-off screen with a slot, as this enables the top of the flame to be accurately gauged. It is, however, a matter of practice, and the writer has never found it a difficult matter to set the height with precision. A variation of 1 millimetre in height of Standards Nos. 1 and 2 makes a difference of $\frac{1}{16}$ th in the power of the flame. In the lamp No. 3 a wick is used and only the lower portion of the flame is exposed. A small variation in the height of flame does not appreciably affect the power of the Standard. In Simmance's Pentane Standard a variation in the height of flame causes rather more difference in the power than Nos. 1 and 2. This is more than compensated for by the fact that this Standard, when adjusted, keeps to a constant length and is very easy to adjust. The writer has had one of these Standards under observation for twelve hours, and there has been no appreciable variation in the height of flame during that period.

(b) *Argand Flames*.—All of these are used with only a portion of the flame exposed. It has been proved by experiment with Dibdin's Pentane Standard that practically uniform results are obtained (other conditions being equal) with the flame varying from $2\frac{1}{2}$ to $4\frac{1}{2}$ inches. A series of tests were made by the Board of Trade Committee which reported in 1895, and the following are the results:—

“A Harcourt Pentane Air Standard (No. 1), with height of flame fixed at 63.5 millimetres, was tested against a comparison flame, giving same a value of 16.1 candles. This comparison flame was then tested against a Dibdin 10-candle Pentane Standard, the flame height of which was varied and measured, and it ascribed the fol-

lowing values to the 16.1-candle comparison flame at the heights stated:

2½-in.,	3-in.,	3½-in.,	4-in.,	4½-in.,	5-in.,	5½-in.	Dibdin flame
16.09	16.08	16.14	16.15	16.14	16.25	16.37	“ “

These figures show that a considerable variation in height affects the power very little. The Harcourt Pentane 10-Candle Standards (Nos. 4 and 5) have flames of a similar class and are stated to be also capable of considerable height variation without making a difference in the power. The writer has seen no figures of any experiments made in this direction. His own experiments with the now official Standard (No. 5) limit this possible variation of height without variation of power very much indeed. This point is dealt with in par. 187.

176. *Effect of Pressure on Power of Flames.*—Mr. Harcourt and Professor Harold B. Dixon carried out many experiments with a view of ascertaining what effect changes in atmospheric pressure have upon the power given by a solid flame Pentane Standard. As a result it was found that

“The heights of flames giving the same light vary inversely with the atmospheric pressure. Thus the flame behaves as if it were a cone of constant base, made of gas, obeying Boyles' law and rendered visible by its incandescence. The volume of such a portion of gas would vary inversely with the pressure, and the height of the cone would vary directly with the volume.”

In the Pentane Standards (Nos. 1 and 2) it was found that for every tenth of an inch by which the barometer exceeds or falls short of 30 inches the Pentane flame is to be set 0.2 millimetre below, or above 63.5 millimetres, which is the standard height at 30" barometric pressure. Now it will be seen that it is an easy matter to adjust the flame height according to the barometer, but if this is disregarded the possible extent of error is as follows: The extreme limits

of barometric variation can be taken between 28" and 32"; i.e., 2" either way. That represents in height of flame 4 millimetres. Now, it has been stated in par. 175 that 1 millimetre height of flame makes a difference of $\frac{1}{16}$ th of the power of same. Therefore, the error in either direction which is possible is one of $\frac{1}{4}$ th, or 10 per cent., the power of the standard being too great when the barometer is high and too small when the barometer is low. It will be seen that the flame can be kept at a constant height and the result corrected—the correction being $\frac{1}{2}$ per cent. for each $\frac{1}{16}$ th of an inch barometer.

With regard to the barometric effect upon the Argand type of Pentane Standards, this has not been closely observed, or, if observed, has not been recorded. The Report of the Board of Trade Committee states with regard to the Dibdin Standard:—

“It seems probable, however, that the value of the standard is not materially affected by such variations of atmospheric pressure as commonly occur.”

The same may be taken as true of the other Argand types.

177. *Effect of Temperature on Power of Flames.*—Variations of temperature of the atmosphere affect the light of Pentane Standards, and should, therefore, be controlled and kept in as narrow limits as possible. (See par. 146.) Variations in temperature of the Pentane do not affect the result of tests, because the difference caused by differences in temperature is one of length of flame, which can, of course, be observed and adjusted. It is not probable that any such change of temperature in the Pentane during a test would occur unless artificially created.

178. *Effect of Humidity on Power of Flames.*—A great many experiments have been made in this direction, and more

particularly with a view to ascertaining if the effect of dryness or moisture on Pentane and coal-gas flames is a parallel one. The late Mr. Methven made a great many experiments on the point, and he found that by taking extreme conditions of temperature and humidity great differences in the light from gas flames were recorded. With a high temperature and a saturation of moisture a reduction of 10 per cent. took place in the light given by an Argand burner, and 12.2 per cent. in the light given by a flat flame. The Committee on Photometric Standards before referred to made experiments on this point and came to the conclusion—after tests extending over seven months, and made upon the one-candle Pentane unit, a 10-candle Pentane Argand, and a London Argand burning coal gas—that,

“Although by abnormally saturating or drying the air supplied to a flame, variations as great as those obtained by Mr. Methven undoubtedly occur, yet in a well-ventilated testing room, with the temperature kept within a narrow range, no such great differences are to be found.”

It will, therefore, be seen that the humidity, like the temperature, should as far as is possible be kept within narrow limits. (See par. 158.)

179. **HARCOURT'S PENTANE AIR-GAS UNIT.**—This one-candle standard, of which a description and illustration follow, was produced by Mr. Harcourt in 1877, has been repeatedly tested, and has been proved to be scientifically accurate, capable of reproduction, easy to produce, susceptible of adjustment for varying conditions, practical in use, and of a power fairly representing the light yielded by one standard sperm candle as defined by Parliament. It has been the basis of comparison of all the Pentane standards since devised. The official 10-candle Pentane lamp, No. 5, is thus equal to 10 one-candle Pentane air units.

180. *The Harcourt One-Candle Standard* is described as follows (Fig. 29.) :—

(a) *The Burner*.—This consists of a brass tube 4 inches in length and 1 inch in diameter, which the gas enters near the bottom. The upper end of the tube is closed by a brass plug, half an inch in thickness, in the middle of which is a round hole a quarter of an inch in diameter.

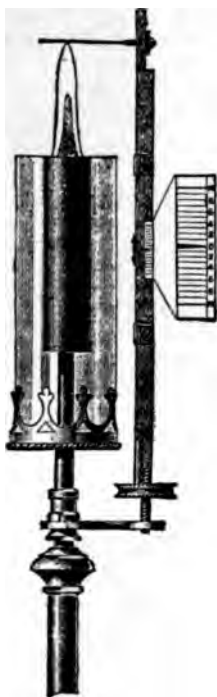


FIG. 29.—HARCOURT'S PENTANE UNIT.

Around the burner is placed a glass cylinder 6×2 inches, the top of which is level with the top of the burner, air entering through the gallery on which the chimney stands. A piece of platinum wire, about 0.6 millimetre diameter and from 2 to 3 inches in length, is supported at a height of 63.5 millimetres above the burner.

(b) *The Air-Gas*.—This is made by bringing together in a gasholder air and liquid Pentane, which evaporates and mixes with the air, in the proportion of 1 cubic foot of air to 3 cubic inches of Pentane. The Pentane used is a mixture of Pentane with some of the paraffins of lower and higher boiling-points, which is prepared by distilling the light petroleum at 60° C., at 55° C., and twice at 50° C. The Pentane thus prepared must satisfy the following tests: On agitation with one-twentieth of its bulk of fuming sulphuric acid for five minutes, it must impart to the acid only a faint brown colour. The density of the liquid must lie between 0.62 and 0.63 at 62° F. The liquid must evaporate at the ordinary temperature absolutely without residue when the tension of its vapour is not less than 7.5 inches of mercury. The density of the vapour, compared with that of air, must be not less than 2.47, nor greater than 2.53.

(c) *Measurement of the Gas and Other Conditions for Obtaining a Light of One Candle*.—For the preparation of Pentane air-gas it is convenient to use a gasholder consisting of a cylindrical bell of about 7 cubic feet capacity, suspended and counterpoised in the usual manner over a tank having an annular space filled with water. A graduated scale attached to the bell serves to measure the volume of air drawn in, and also the volume of vapour formed from the measure of Pentane which is discharged from a pipette through a tap into the holder. Three cubic feet of air (corrected for the actual conditions under which the air is measured) and 9 cubic inches of Pentane (measured at 62° F.) yield, after standing for some hours, a volume of air-gas which (corrected to standard conditions) should not be less than 4.02, nor more than 4.1 cubic feet.

The air-gas should pass to the burner through a small meter delivering at each revolution one-sixtieth of a cubic foot. The flame having been set at the standard height, the meter is read two or three times at intervals of two minutes. A testing should be rejected in which the rate of the air-gas has exceeded 0.52 cubic foot, or fallen short of 0.48 cubic foot per hour.

After the meter, the air-gas should pass through a small governor of the usual construction, fitted to regulate a flow of half a cubic foot per hour.

The height of the flame is to be adjusted by means of

a delicate stop-cock, by gradually raising it until the top appears to touch, but not to pass, a horizontal platinum wire, which must be placed exactly over the flame, and extend not less than half an inch beyond it.

Since the apparent position of the tip of the flame varies slightly with the sensitiveness of the eyes of the observer, and the principal variations in sensitiveness are due to the greater or less exposure of the observer's eyes to light, both during an observation and for some time previously, it is necessary to define the conditions under which the height of the flame is to be judged.

For photometry in which the relative illumination of two adjacent surfaces is compared, the observer must be in a darkened room and screened from the two sources of light. In the screen which is between the observer and the one-candle flame there should be an opening whose horizontal length is about 1 inch and its width about one-quarter inch, at the same level as the top of the flame. Through this slot the observer looks, lowering his head until he sees only the tip of the flame and the wire extending above it. Behind the flame and wire the background should be as uniform and dark as possible.

This standard having received legal sanction (as the unit of the present standard for the metropolis), naturally is extremely important; but, notwithstanding this, the writer believes himself to be the only person in the kingdom who maintains the standard apparatus for reference by the public and experimentalists at any time. It would appear strange that the government, which preserves copies of other (and less important) measuring standards, which are accessible to the public, has not taken similar steps in this most important matter.

181. *Harcourt One-Candle Pentane Lamp No. 2.*—This was the outcome of a very natural desire on Mr. Harcourt's part to reproduce his Pentane air-gas flame in a portable form. The lamp was difficult to adjust and required a great deal of attention. It is described by Mr. Harcourt as follows (Fig. 30):—

“In this lamp the Pentane burner already described was attached to the shorter limb of a syphon, the upper limb of which was passed into a reservoir partly filled with liquid Pentane and covered by a loosely fitting lid. Within this reservoir the Pentane evaporated, and its vapour, mixing with the air, poured down the long limb of the syphon and out of the orifice of the burner. The

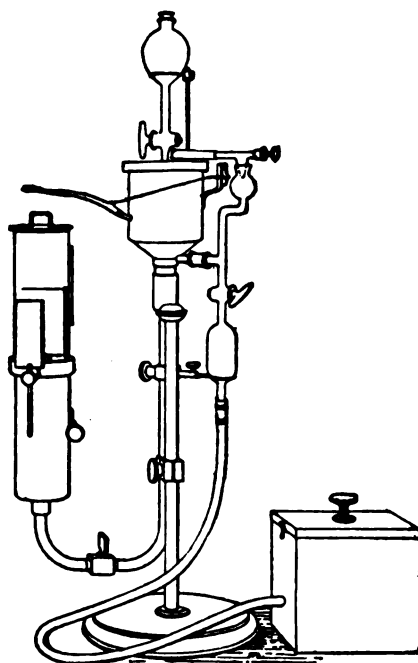


FIG. 30.—PENTANE UNIT, PORTABLE.

through-way of the syphon was constricted at one point—originally by a perforated diaphragm and afterwards by a tap—and the diameter of the perforation, in conjunction with the effective length of the syphon and the height of the flame, determined and fixed the composition of the mixture of Pentane and air. These adjustments were made, in the first instance, by comparing the light of the lamp with that of the Pentane standard. When the flame of the lamp was set to the height of $2\frac{1}{2}$ inches, which

could be done by raising or lowering the Pentane in the reservoir, if its light equalled that of the Pentane standard, the thing required was done. But if not—to follow the method of Euclid—the light was either greater or less than that of the Pentane standard. If it was greater, the mixed gas was too rich. This could be remedied by enlarging the perforation of the diaphragm or plug. The immediate effect of such enlargement is to lengthen the flame; and when, by lowering the Pentane in the reservoir, the flame is again reduced to $2\frac{1}{2}$ inches, the mixed gas passing down the syphon is less rich in Pentane, and the light of the flame will be less. If, on the other hand, the flame of the lamp was less bright than the Pentane standard, the perforation was too large, and must be contracted. In this way, by repeated trials, the exact size of the perforation was discovered, which, with a fall of 6 inches, would let pass a mixture of air and Pentane in such proportions and quantity as would give a $2\frac{1}{2}$ -inch flame of the same brightness as the Pentane standard. This adjustment is of great nicety, and, once arrived at, fixes absolutely the composition of the Pentane gas burned in the lamp. For, if the Pentane gas is too rich, two causes will operate in making the flame longer. If the richer gas flowed from the burner at the usual rate, it would give a longer flame, on the well-known principle of the jet-photometer; but the richer gas is also denser, and, therefore, will pour down the syphon and out at the mouth of the burner more rapidly than the mixture of air and Pentane in the right proportions. Similarly, if the Pentane gas is too poor, the same causes contribute to shorten the flame.

182. Various improvements were made in this lamp between the years 1883 and 1887. The modes of carrying heat from the flame to the reservoir, so as to vary at will the rate of evaporation of the Pentane, and of supplying Pentane to the reservoir, were gradually improved, so that with a little practice the maintenance of the flame with its tip exactly touching a horizontal wire $2\frac{1}{2}$ inches above the burner became fairly easy. The experience of photometry near the open window of a wooden hut on the S. Foreland led subsequently to the devising of a glass chimney with a perforated brass lid, through which the light of the flame was the same as the light of the naked flame. So protected, the flame is much steadier

than a candle flame (Fig. 31). The unprotected Pentane flame, steadied by a cylinder, which surrounds the burner, is rather more affected by draughts than the flame of a candle. There is, however, this difference, that when

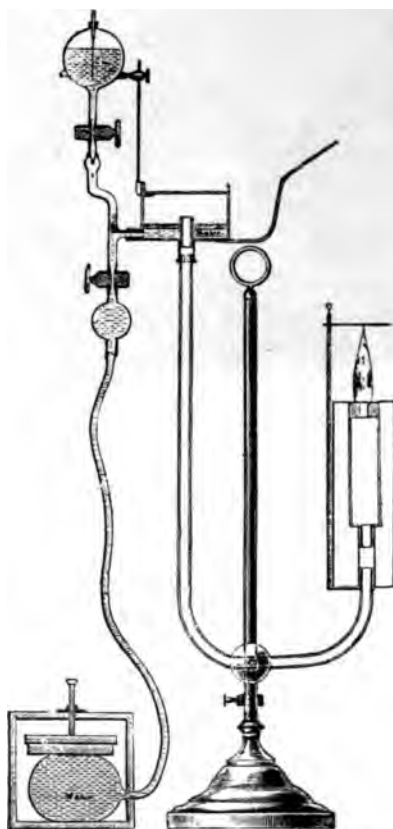


FIG. 31.—PENTANE UNIT, PORTABLE (IMPROVED).

the draught has ceased or been stopped, the Pentane flame has at once its former position and value; whereas a transient draught fills the cup of a candle and snuffs its wick, and thus changes its light for several minutes afterwards. In spite of the instability of the Pentane flame, it was found possible, by a suitable arrangement of curtains,

to use the Pentane lamp for photometry in the temporary huts on the South Foreland even on windy nights."

183. *Harcourt's Pentane Lamp No. 3.*—This lamp is an improvement on the preceding one, being easy to handle and adjust. It will be seen from the following description, instruction, and illustration that a wick is used as a conductor, and a long series of tests showed it to give a light practically equal to the Pentane Air-gas flame No. 1.

"The lamp (Fig. 32) consists of a glass reservoir, with tubulure and stopper, of the form and size of a spirit lamp, mounted on a metal stand which rests on three levelling screws. The wick is turned up and down in the usual manner by means of a double-toothed wheel, the spindle of which fits air-tight into the tube which supports it. The lower end of the wick, which is one of the round wicks now largely used, of rather less than one-quarter inch diameter, lies covered by Pentane in the reservoir; the upper end is in a brass tube, about five inches in length, in which it can move up and down freely. The upper part of the tube is surrounded by a wider tube, about four inches in length and one inch in diameter; and the two tubes being joined together above and below by flat plates, constitute the burner of the lamp. Around the burner is another cylinder, open at both ends, of about two inches diameter, surrounded at the level of the top of the burner by a conical piece, terminating in a short tube, whose diameter and length are about three-quarters of an inch. Over this outer casing is a similar piece, inverted, with the smaller tube below and the larger above. This second piece is connected with the first, the two being attached by two semicircular bands, so that the ends of the smaller tubes may be set at different distances apart, according to the amount of light it is desired to obtain from the lamp. All these tubes, whose purpose is to partially enclose and steady the flame of the lamp, have a common axis. Through opposite sides of the upper tube and above the ends of the connecting bands are cut two narrow slots about one-eighth of an inch in width and one-half inch in height. These are placed at such a height that, whenever the top of the

flame is visible between them, the light of the lamp shining through the interval between the small tubes is definite and constant. Thus the adjustment of the height of this flame is a matter of much less delicacy than in its predecessor. In the former lamp a variation of 1 millimetre



FIG. 32.—PENTANE 1-CANDLE WICK LAMP.

in the height of the flame made a difference of one-fortieth in the light which it gave; in the new lamp the height of the flame may vary nearly 10 millimetres without the light of the lamp being appreciably affected. The adjustment of the light, which may be set at half a candle,

one candle, or one candle and a half, is effected by means of cylindrical brass blocks, whose thickness has been carefully adjusted once for all. One of these blocks is placed upon the lower tube, and the upper tube is lowered until it presses gently against the block; the screws which fix the connecting bands are then tightened, and the block is withdrawn. Since the blocks are made of the same diameter as the tubes between which they are placed, they serve for setting these tubes truly on the same axis as well as at the right interval apart, for, when the block and the tube are in the right position, the fingers slide smoothly over the edges, which exactly coincide.

"The point, or rather the horizontal ring, from the nearest point of which measurements are to be made when the flame of the lamp is used as a photometric standard, is midway between the tubes which surround the flame and at a distance of half the radius of these tubes from their axis, which is also the axis of the flame. This position is defined to the eye by giving to the curved connecting bands half the width of the tubes. The zero of the photometric scale lies in the plane which passes through the edges, on either side, of the connecting bands. To mark the plane by a solid surface, a rectangular strip of brass is provided, which can be fitted on one side into the centres of the edges of the connecting bands. A small plumb-line is also provided, by means of which the lamp can be set truly vertical, and a small mirror, by means of which the photometrist can observe without changing his position, whether the top of the flame is between the slots in the side of the chimney.

184. The following are the instructions for using this Standard:—

Before commencing to use the lamp, take care that the plug which closes the burner hole is removed.

The glass vessel should be half filled with Pentane and the stopper carefully replaced, so that no leakage of vapour shall take place.

The surface of the stopper may be slightly moistened with glycerine.

The wick may be screwed up till it becomes visible at the top opening, and then depressed about $1\frac{1}{2}$ inches. Do

not move the wick, except when it is moistened with Pentane.

To set the height of the movable chimney, take the gauge it is intended to use, and lay it on the top of the lower cylinder. Let the chimney drop upon it, and adjust with the fingers till the edges are flush with one another.

Secure the chimney by means of the side screws, and carefully slip out the gauge.

To Light the Lamp.—The lamp may most easily be warmed and lighted without displacing the chimney by inserting the cotton ball, dipped in spirits, between the outer cylinder and the burner, and leaving it for a minute or till the spirit is nearly consumed. In cold weather a second application may be necessary. When once the lamp has been lighted its flame maintains the heat.

The flame should pass up into the chimney, and its tip should be visible between the upper and lower edges of the slots cut in the chimney. It may be lowered or raised by the movement of the wick.

So long as the tip of the flame remains between these limits, the light given by the visible portion of the flame below will be exactly that marked upon the gauge used.

For the purpose of seeing the height of the flame conveniently, the small piece of glass is to be slipped into the socket attached to the side support, and it can be turned to such an angle as the observer may wish.

To Level the Lamp.—Slip the small arm, to which the plumb-bob is attached, into the socket which also holds the glass. Adjust the levelling screws so that the line nearly touches the surfaces of the two projecting pieces of metal on the cylinder and passes through the two points of intersection of the lines cut on each of them.

The lamp should be fixed at the end of the Photometer bar, so that the zero of the scale is in the same vertical line with the face of the small metal plate, which should be inserted into the slots cut to receive it in the two side supports.

To prevent loss of Pentane vapour when the lamp is not in use, take care that the plug is replaced in the burner hole.

185. *Harcourt's Ten-Candle Pentane Lamp No.4.*—This was a 10-candle lamp with a wick to conduct the Pentane,

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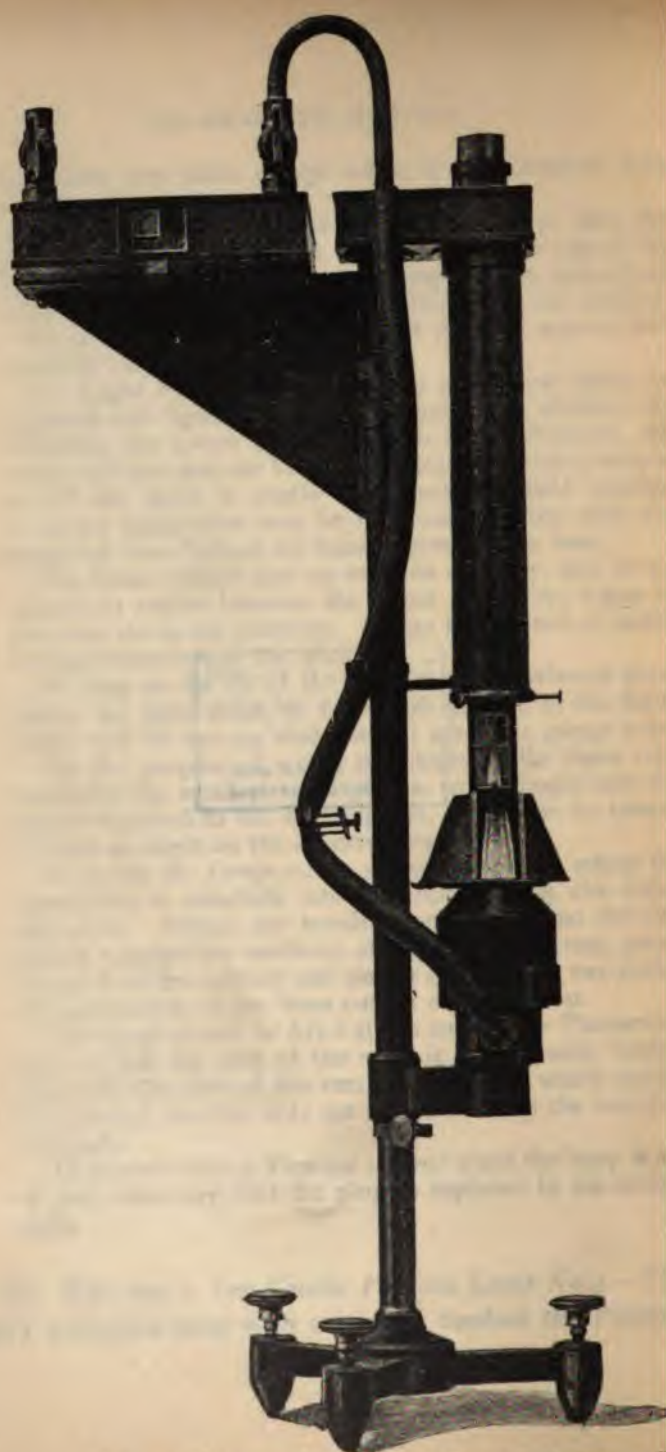


FIG. 33.—HARCOURT'S 10-CANDLE PENTANE LAMP.

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so that it could be vapourised by the heat of burner and consumed in the Argand. It was described by Mr. Harcourt before the British Association in August, 1894, and forms the link between the 1-candle lamp and the official 10-candle lamp referred to in the following paragraph. It has not, so far as the writer is aware, passed into practical use, being superseded by the latter.

186. *Harcourt's Official Ten-Candle Pentane Lamp.*—This lamp is a chimneyless Argand burner (No. 5), consuming Pentane gas of a Standard quality. This 10-candle Pentane lamp, being built upon the experience gained with the various forms of Mr. Harcourt's Pentane Standards and of Mr. Dibdin's Pentane Argand, avoids the difficulties which were found to stand in the way of the practical and everyday use of these. It is difficult to give a definite opinion upon a standard of light which has only been in use for a short time, but the writer's experience leads to prove that, although the Harcourt Pentane lamp is convenient and, in the practical sense of the term, constant, and of a light value equal to 10 candles, yet it does not appear to be totally independent of those different atmospheric conditions which are produced by ventilation, or the want of it, and the details of its construction might be improved upon. The fault with the lamp seems to be the difficulty in getting a clean-topped flame, and on this account the variation in the sizes of flame through which the power of light is correct is very limited, and there is the chance of the mean height of the flame being adjusted at too low or too high a point when the power of the Standard is altered. It is purely a question of the personal error, but one which seems likely to occur for the reason above stated. The impression the writer wishes to convey is not that the power of the Standard is susceptible to variations to any great extent, but that the selection of a properly ventilated and heated room

is still a matter of importance, and that, because the Standard is simple and portable, it must not be supposed that it can be set up and used with satisfactory results in any room of inadequate size and construction. For details of this Standard and its use with the Table Photometer see pars. 122 *et seq.*

187. It will be understood that the remarks in pars. 173 to 178 apply to all of the Pentane Standards described above, and also to the Dibdin 10-candle Pentane Argand and Simmance's Pentane Standards, a description of which follows (Fig. 34):—

188. *Dibdin's Ten-Candle Pentane Argand.* — This Standard is an important one—although it has been superseded and will probably fall out of practical use—because it was the forerunner of the 10-candle Standard now adopted for official use in London, Birmingham, Hastings, and elsewhere. It is not an exact standard, and has two faults: firstly, because the use of the air holder renders it unportable, and secondly (and this constitutes its inexactness, unless provided against), because the use of the glass chimney makes the power of its light an uncertain quantity. It has been found that different chimneys affect the light yielded to an extent sufficient to cause appreciable errors, and that even turning the chimney round makes a difference in the light. At the same time, every credit is due to Mr. Dibdin for its inception, and when it was recommended by the 1895 Committee of the Board of Trade it was, perhaps, the most practical 10-candle Standard extant. It consists of a screened Argand burner of special construction, the bottom of the screen being 2.15 inches from the top of the steatite. It burns Pentane air gas made by passing air from a small holder over a modified form of Hartley's carburetter in which Standard Pentane is placed. The burner is surmounted by a chimney 6 inches high by $1\frac{1}{2}$ inches internal

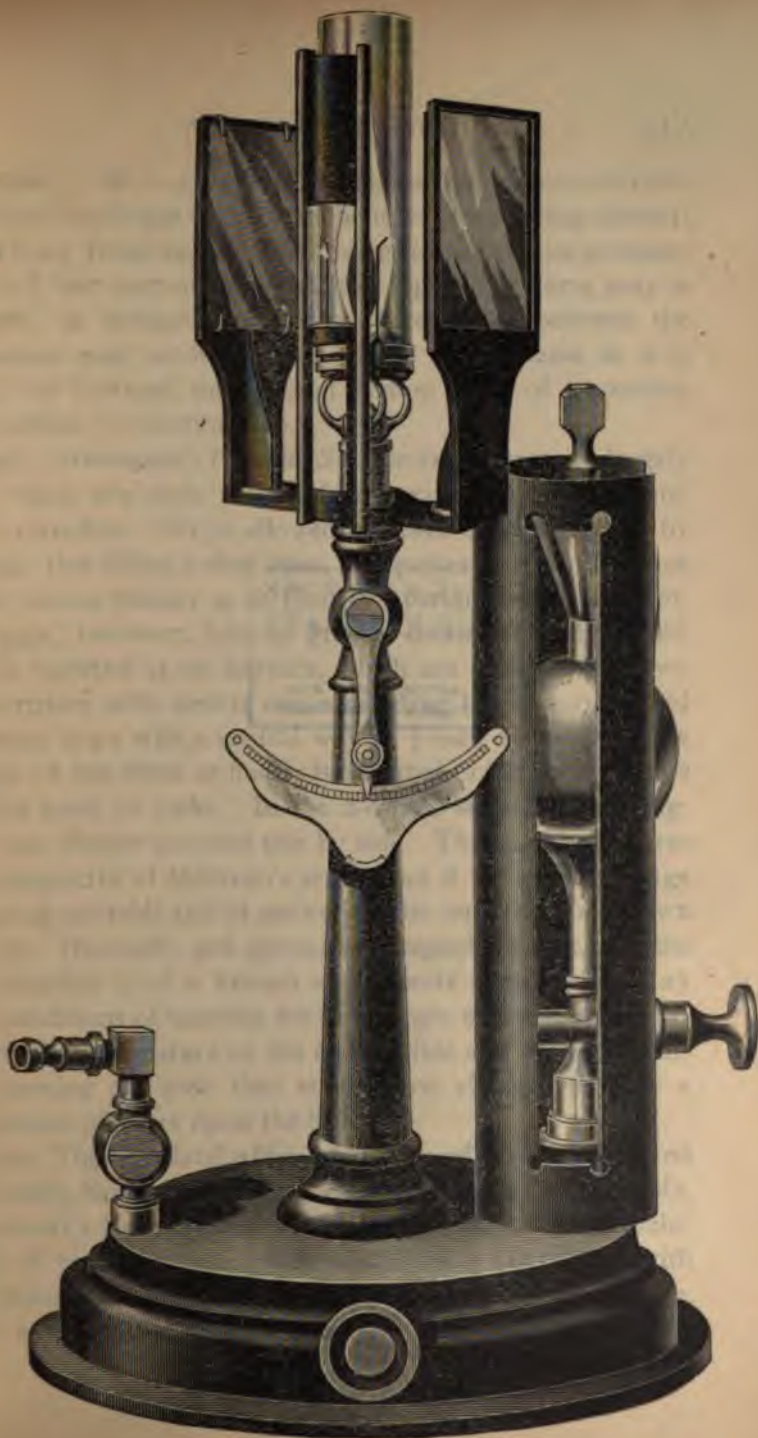


FIG. 34.—DIBDIN'S PENTANE ARGAND.

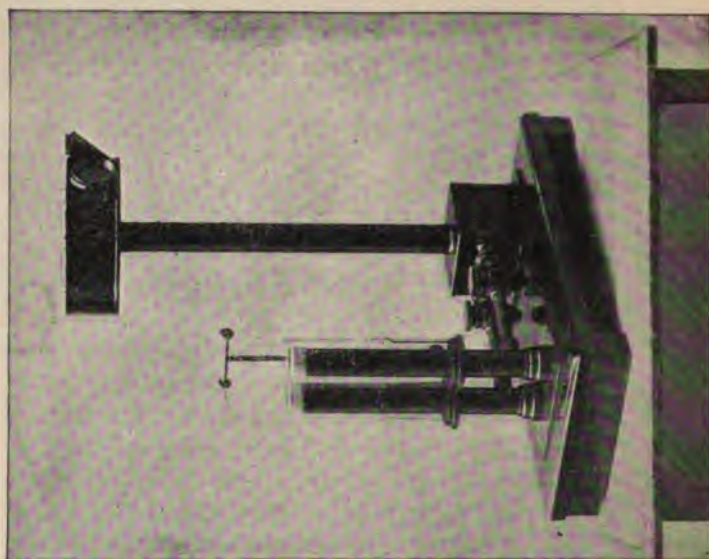
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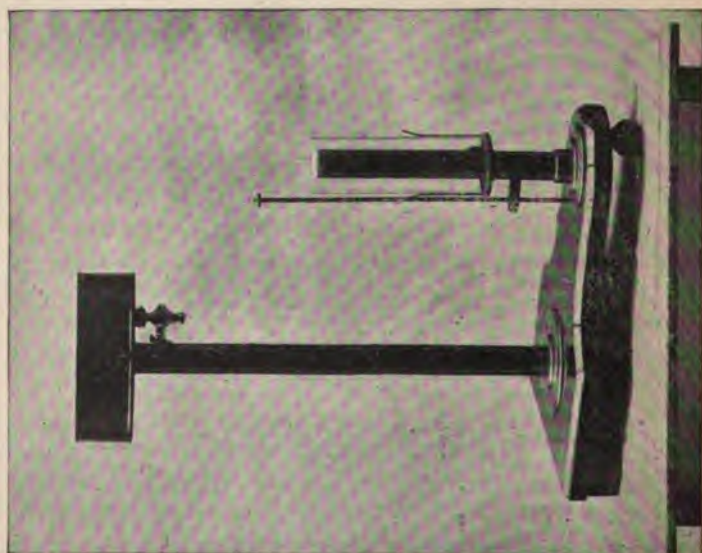
diameter. It is, as before stated, capable of considerable variation in height of flame without its power being altered; this arises from the fact that, owing to the peculiar arrangement of air currents and that the top of the flame only is cut off, a compensating action takes place between the luminous and non-luminous portions of the flame as it is raised or lowered, the exposed portion being of a constant light value, or practically so.

189. *Simmanse's Pentane Standards*.—These are largely used, and are made in two forms, viz., for 1 candle and for 2 candles. Air is allowed to enter the carburetter by leaving the filling socket open, and passes over the Pentane in the same manner as in Hartley's carburetter. The Pentane gas, however, falls by gravity down the upright tube and is lighted at the burners, which are either one or two brass tubes with steatite non-conducting blocks surmounted by brass tops with a central way of $\frac{1}{4}$ -inch diameter. The height of the flame or flames is adjusted to the height-gauge by the cock or cocks. In the 2-candle standard (see Fig. 35) two flames are used side by side. This standard shares the simplicity of Methven's screen, but it has the advantage of being portable and of answering the conditions laid down by Mr. Harcourt, and generally accepted, in that (1) the combustible is of a known and definite composition; (2) the conditions of burning are of a simple and definable character; (3) the nature of the combustible and the conditions of burning are such that atmospheric changes produce a minimum of effect upon the light.

190. The Standard which was produced early in 1896 and avowedly based as regards the form of burner tube on Mr. Harcourt's No. 1 Standard, is largely used, and is undoubtedly of very great use where reliable tests are desired with a minimum of trouble. Being self-contained and portable, and easily adjusted, it is especially useful for works tests



1 CANDLE. FIG. 35.—SIMMAN'S PENTANE STANDARDS. 2 CANDLES.



and for tests with portable Photometers. This Standard is also useful for alternative use with the sperm candles, the

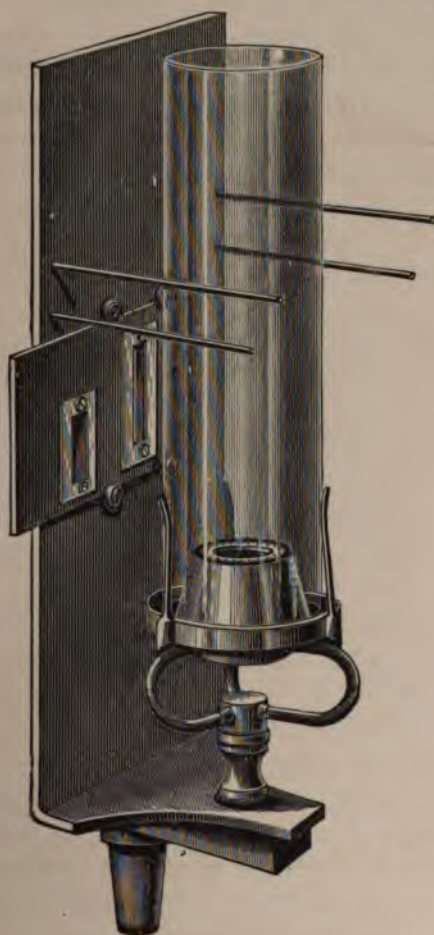


FIG. 36.—METHVEN SCREEN.

base of the candle balance table and of the Simmance Standard being made so as to be instantly interchangeable and

bring the flames of both to the correct centre and position. This Standard was described in a paper read by Mr. Pryce before the Incorporated Institute of Gas Engineers in the summer of 1898 (see proceedings).

191. *Methven's Screen*.—Another Standard which is in very general use—in fact, to a greater extent than any other Standard of Light except candles—is the Methven Screen. This was produced by the late Mr. John Methven about 1878. (Fig. 36.) It is simply an Argand burner placed behind a screen, which is pierced with a slot of definite proportion, through which the light rays pass. Ordinary coal gas is burned in the Argand, the flame being adjusted to 3" in height, and surrounded by a 6" × 2" chimney. Provided that the coal gas used is of ordinary quality, between 14 and 18 candles, the height adjusted carefully, the screen tested with the chimney with which it is to be used, the position of the chimney being marked, this Standard is an admirable one, and undoubtedly very convenient for experimental use. The fact, however, that the "combustible" is an unknown quantity has prevented it from being adopted as the official Standard. The screen is made with a secondary slot and height-gauge, the latter being 2½" high and with this slot practically any quality of gas previously carburetted with Pentane can be used, and with accurate results. This arrangement is absolutely necessary where the gas that is being burned in the Methven Argand contains any water gas, but even with the addition of the carburetter, which is a small and simple one, it will be seen that the Standard is useful, reliable, and very easily manipulated. The chief use to which the Methven screen is put for alternative tests with candles in an open Photometer fitted with the arrangement described and illustrated in par. 27, so that the unofficial tests can be taken by the

Methven screen and the candle balance, upon which the official tests are made, instantly substituted when desired.

192. Where a Photometer is fitted with the tri-arm it will certainly be found a great saving of time to use the screen in this way; but where this arrangement is not fitted, and particularly where water gas is used, in the writer's opinion the most convenient form of Standard for alternative use with the candles is the Standard Harcourt 10-candle lamp or Simmance's 2-candle Pentane burner. The necessity of carefully adjusting the height of the Methven screen flame and of using a properly tested chimney cannot be insisted upon too strongly.

193. The following are Standards of light to which passing reference must be made. With one or two exceptions, these standards are not in practical use in this country, but the brief notes will probably be found useful:—

194. *Violle's Molten Platinum*.—This is a standard in which the light measured is that yielded by a square centimetre of molten platinum in a solidifying state, and is taken as a standard unit. The report of the British Association Committee in 1888 rejected the standard as an impracticable one. Attempts were made to produce a simpler modified form, but without success. Its light value is 20.8 candles.

195. *Sugg's Ten-Candle Standard*.—This is a variable standard, the variation in which can be measured. It consists of an experimental meter surmounted by an Argand burner in which a certain height of flame is cut off. From the amount of gas taken to yield this height of flame the value of the light given is ascertained by means of a table. The "combustible," as in the case of the Methven screen, is an unknown one, and water gas and various modern methods of enrichment in the gas used destroy the accuracy of this test. Where the proper conditions for which it was ar-

ranged obtain, the Standard is a reliable one for ordinary use, but cannot be used officially.

196. *Keate's lamp* was an oil lamp in which sperm oil was consumed, and the height of flame regulated by the wick, and was arranged to give a 16-candle light with a 2-inch flame when burning 925 grains per hour. It will be understood that the lamp had to be weighed for consumption of sperm, and corrections made for various consumptions. Mr. Dibdin was a warm advocate of this Standard, but obviously the disadvantages were many, and, like Mr. Dibdin's own Pentane Argand, it had to give way to the more convenient Methven screen and Pentane Standards.

197. *Fiddes' Standard*.—Before passing to a description of one or two standards in use abroad, attention is drawn to the following, which will doubtless be of great interest:—

In the course of some experiments, made in 1866 with a view of employing polarization for photometrical purposes, Mr. William Fiddes (then nineteen years of age, serving his articles to the Bristol United Gas Light Company) noticed the fact that the same area of a flame in the same part of the flame had practically a constant photometrical value, no matter what gas was employed, so long as the gas did not fall below 10 candle power.

The flame employed by him in his experiments was the ordinary Argand, having a height of $3\frac{1}{2}$ inches. This was surrounded by a brass chimney 2 inches in diameter and 8 inches high. At a height of $1\frac{3}{4}$ inches above the burner the cylinder was perforated by a circular orifice having a diameter of three-eighths of an inch. The light issuing from the orifice was found to be equivalent to that emitted by one candle, as the following observations demonstrated:—

Illuminating Power of the Gas Experimented on.	Value of Light Emitted from Orifice, Expressed in Terms of One Candle.
13.00 Candles	1.000
19.00 "	1.000
16.60 "	0.985
12.64 "	1.000
17.80 "	1.005

Numerous other experiments were made with equally good results, but of which no record was kept.

198. The writer hopes to find time shortly to make further experiments on lines suggested to him recently by Mr. Fiddes, with a view to ascertaining whether a gas standard with a Fiddes screen for technical purposes cannot be brought into practical use.

199. *The "Carcel" lamp* is a colza oil lamp with an annular wick and burner, the oil being forced up by a small clock-work pump. The light given by the consumption of 42 grammes of sperm an hour equals 1 carcel, and (as in the Keate's lamp) the lamp is weighed for consumption of sperm and corrections made. The height of the wick should be from 8 to 10 millimetres, and the shoulder of the glass chimney about 7 millimetres above the wick, while the flame is about 38 millimetres. Each lamp is, however, tested before being sent out, and the first two of the above dimensions varied in order to bring the consumption of sperm within the limits of 38 to 46 grammes per hour. It is stated on the authority of M. Monnier that the consumptions should be limited between 40 and 44 grammes of sperm per hour. Refined colza oil is used; a new wick is necessary for each test; the oil must be filled up to the prescribed level, and the lamp must burn half an hour before the readings are taken.

200. The Carcel lamp is the French Standard of Light (saving the stearine candle), and is used in comparison with a porcelain Bengel gas burner having 30 holes, and

of prescribed dimensions. The pressure at point of ignition of this burner is from 2 to 3 millimetres of water and the method of testing is to adjust the flames of the Carcel lamp and the gas burner until equality of illumination is observed, and then correct for the variations of both lamp and burner from prescribed rate, the former by weighing, the latter by measurement. The standard consumption of sperm is 42 grammes per hour, which is equivalent to 10 grammes in 14 minutes 17 seconds. The standard rate for the gas is 105 litres per hour. The correction for sperm is made as follows:—

Take the time occupied by the lamp burning 10 grammes. (If outside 13 minutes 38 seconds and 15 minutes, test is rejected.) Divide the time taken by 14 minutes 17 seconds. The result is in terms of 1 carcel. The correction for the gas is inversely proportional to its rate, that is to say, the greater the consumption, the less the illuminating power, and *vice versa*.

The writer believes he is correct in stating that the French system of thus varying the rate of gas to give a standard light formed, to a great extent, the precedent for the finding of the '95 Standards of Light Committee (see par. 112), and for the Referees' subsequent adoption of the method with the Table Photometer. The value of a Carcel may be taken as being between 9.5 and 10 standard sperm candles.

201. *The Stearine Candle* (French).—This candle, called *l'étoile*, is not in ordinary use. They are made to consume 10 grammes of stearine per hour, and give a light equal to about 1.4 English candles.

202. *The German Standard Paraffin Candle*.—The Standard of Light in Germany is a paraffin candle, 10 candles to the $\frac{1}{2}$ kilo. The candles are made of pure paraffin with a little stearine added. The diameter, melting point, strands of wick, and weight of same are all closely defined.

but the candles are, of course, subject to the same objections as our sperm candles. The light of one of these candles is equal to 1.05 Standard Sperm Candle. Full particulars of a special candle, distinguishable by a red strand in its wick and called the "Association" candle, are to be found in the records of the German Gas and Water Association.

203. *Hefner-Alteneck Lamp* (Amyl-Acetate).—Another Standard of Light largely used in Germany is the amyl-acetate lamp invented by F. von Hefner-Alteneck. It is known to experimentalists in England, but does not find favour on account of the reddish light it gives. It has the advantage that its "combustible" is a known quantity, being amyl-acetate, which is prepared by the distillation of amyl alcohol with sodium acetate and sulphuric acid. The lamp has a wick, and the flame is produced by burning amyl-acetate. It is adjusted to 40 millimetres in height, and yields a light of between 0.8 and 0.9 Standard candle. This Standard has been examined by one of the British Association Committees, but was rejected on account of the colour difficulty. This Standard is practically superseding the paraffin candle in Germany.

204. *Dutch Standard*.—There is yet another Standard in the form of a lamp with a wick burning a mixture of benzene and ether. It has been found by the Dutch Committee which produced it to give a constant light, and there is no reason why this should not be so. It gives a light of 1.48 candles. It is used in conjunction with a special system of photometry, involving novel details, the particulars of which, as published in a special report of the 1883 Dutch Committee on Photometry, will be found interesting.

205. The following summary of the Standards of Light referred to in the preceding paragraphs will serve for purposes of reference. There are many other Standards of Light, suggested or in actual use, and the writer trusts that

in taking the above list he may be considered to have been guilty of neither sins of commission nor of omission.

Standard sperm candle.....	1 candle	par.	171
Harcourt's Pentane air-gas unit	1 "	"	179, 180
" 1-candle Pentane lamp, portable...	1 "	"	181
" 1-candle Pentane lamp with wick..	1 "	"	182-184
" 10-candle Pentane lamp with chimney	10 "	"	185
" 10-candle Pentane standard lamp...	10 "	"	186
Dibdin's 10-candle Pentane Argand	10 "	"	188
Simman's 2-candle Pentane burner (twin unit)	2 "	"	189, 190
Simman's 1-candle Pentane unit	1 "	"	189, 190
Methven's 2-candle screen....	2 "	"	191, 192
Violle's molten platinum.....	20.8 "	"	194
Sugg's 10-candle variable standard	{ 10 " consumption variable }		" 195
Keate's sperm lamp.....	16 candles	"	196
Fidde's screens.....	2 "	"	197, 198
" Carcel " lamp.....	10 " (nearly)	"	199, 200
Stearine candle (French)....	1.4 "	"	201
Paraffin " (German)....	1.05 "	"	202
Hefner-Alteneck amyl-acetate lamp	{ between 0.8 and 0.9 candles }		" 203
Dutch standard lamp	1.48 candles	"	204

206. It may be repeated that, so far as England is concerned, the Harcourt 10-candle Pentane lamp and the Standard candles are the two official standards whose use is authorised; that the original 1-candle Pentane air-gas flame is the unit which can always be reproduced for reference; that for unofficial use the Simman Pentane Standards and the Methven Screen with carburetter can, under all circum-

stances, be used with confidence, and that under certain conditions the Dibdin Pentane Argand and the Sugg 10-candle Standard may be useful. It will be readily conceded that the thanks of gas and public authorities are due to Mr. Harcourt for his untiring perseverance, and it is to be hoped that his labours and interest in his Standards of Light, which have been, and are, purely academical, will receive the recognition they deserve.

[NOTE.—Pars. 207-219 are left blank to facilitate additions in a future edition.]

CHAPTER IV.

*CALORIMETRY AND SPECIFIC GRAVITY.**WITH A NOTE UPON MOND GAS.*

220. There has arisen in recent years a set of economic circumstances in connection with the manufacture and distribution of gas, differing in many respects from those which obtained a few years back.

Then, the principal use to which gas was put was for yielding illumination by combustion as a luminous flame.

Now, the uses to which gas is put are:

1. As a means for imparting incandescence, and thus illumination, to what are commonly known as "mantles."
2. As a fuel for cooking and heating stoves.
3. As a fuel for imparting heat to water, as in "water-heaters."
4. As a fuel for gas-engines and other industrial purposes.
5. As an open-flame illuminant.

It is very evident, therefore, that a factor in the value of gas, always important, now essential, is its heating power, or calorific value.

221. What is here aimed at is to lay down clearly the lines (as they appear to the writer) upon which those engaged in the manufacture of gas might with advantage proceed in order to cope with the new set of circumstances referred to above.

The issue is not a very clear one because, in seeking for a high calorific value per £ spent in production, gas

makers cannot ignore the question of illuminating power; but it is at the same time evident that the balance of the one to the other is daily changing. To put it broadly, the question formerly was, "*What is the cheapest method of producing a gas of good illuminating power?*" while the one that is daily increasing in importance is, "*What is the cheapest method of producing gas of adequate calorific power which will at the same time comply with statutory requirements as to illuminating power?*"

222. The instruments required for an exhaustive and analytical investigation of the calorific power of gas are, not only a Calorimeter for gaseous and liquid fuels, but a Photometer and a gas analysis apparatus, and with these the following investigations can be made:

(a) A complete series of tests with unenriched coal-gas, with figures as to illuminating power and cost per candle; with figures as to calorific power and cost per unit (either calorie or B. T. U.), and a comparison between this latter and the sum of the theoretical value of the constituents as ascertained by analysis. (See the tables in Appendix.)

(b) The effect of a series of variations in the method of carbonisation, condensation, and subsequent treatment, with a view to ascertaining whether the heat value can be increased substantially even at the cost of a slight loss in illuminating power:

(c) A series of enrichment tests, with figures as to comparative costs of increase in lighting and heating power, and a comparison of these latter figures with the theoretical heat values of the enrichment materials.

(d) A series of experiments on travelled gas of different composition (the original lighting and heating values of which were known), with figures as to deterioration (due to travelling), both of lighting and heating power.

(e) A comparison of the effective results in actual, ordinary use (see par. 220 [1], [2], [3], [4], and [5]) yielded by gases of varying qualities.

The fact that it is possible to obtain the calorific equivalent of coal carbonised, and also that of not only the gas pro-

duced but of the residual coke, tar, etc., clearly points to the necessity of such comparative tests being made (and they can be made with ease). By this means a knowledge can be obtained of the efficiency of carbonisation, as the sum of the calorific equivalents of the gas and bye-products can then be expressed in terms of the calorific power of the coal originally taken, and thus different methods of working compared. The method of finding the calorific power of solid fuels is described in chapter 6, and it is recommended that such tests be carried out in addition to those mentioned above. The importance of this will be the more readily recognised after perusal of the remarks upon gas engine testing and upon Mond gas. Assuming that the analysis of the gas is a matter which could only be undertaken under certain circumstances, and putting this, therefore, on one side, the remaining data resultant from the series of tests mentioned above (and for the accomplishment of which time alone is necessary, and not expensive apparatus or specialised training) would provide us with a knowledge not only of "*what is the cheapest method of producing gas of high calorific power,*" but also of "*how to produce gas of a given calorific and illuminating power.*"

223. The point that will immediately occur is as to whether there is a constant ratio between illuminating power and calorific power, and seeing that the reply is a qualified negative, the following considerations of the five subdivisions of paragraph 220 must be borne in mind.

224. (1) *Gas for Incandescent Burners.*—The efficiency of gas for use with mantles does not entirely depend upon the calorific power. The flame heat influences the illumination produced by a mantle. The temperature of the flame depends to a great extent upon the amount of air required in combination with the gas for its complete combustion, and the smaller the amount of air required the higher will be

the temperature of the flame, within limits, of course. There is, therefore, to some extent, a balance set up between a gas of lower calorific power, requiring less air for its combustion (as carburetted water gas), and a gas of higher calorific power, requiring more air. The insuring of this efficient degree of air admixture depends upon the construction of the burner, but the facts stated have been supported by experiments, which show that a greater illuminating power has been developed in an incandescent burner properly treated as regards air admixture with gas of a low calorific power than with gas of a higher calorific power. Some recently published experiments of Russell and White do not, however, bear out this result, but do not disprove the statement made above as to the relative influence of flame heat and calorific power. It is certain that the difference in results obtained from incandescent burners with gas depreciated by a few candles is nothing like so great as is the relative deterioration of results from flat flame or Argand burners. That is to say: taking the life of a mantle, it would undoubtedly be better for a customer, for the purpose of incandescent lighting, to obtain cheap 12, 13 or 14 candle gas, if due attention is paid to the air admixture, pressure and mantle texture, than to pay for expensive enriched gas. The tables in the appendix (O) show that with many gases there is a better yield of *calories per candle* if the quality is low than if the illuminating power is high; that is to say, there is a tendency for the illuminating power, up to a certain point, to fall off out of proportion to the fall in calorific power. It is, therefore, evident that there is not a parallel effect upon open flame and incandescent burners when the candle power is reduced (see also tables as to this point in appendix referred to above). Whatever may be the different data which we have at our disposal, it is open to doubt whether, with the loss of a few candles in illuminating power of gas tested in

a Standard burner, there is any practical lessening in *candle-power-mantle-hours* if, as before stated, due regard is paid to proper air admixture, pressure, and texture of mantles.

Dr. H. Bunte, in a communication to the 1900 International Gas Congress in Paris, explains the disproportional light-yield from open flame and incandescent burners for different illuminating power gases as follows:

It will be seen constantly that great changes in the composition of the gas, which reduce the illuminating power in flat-flame and Argand burners by more than one-half, or considerably increase it, and likewise greatly alter the calorific value of the gas—such changes as the admixture of hydrogen, marsh gas, and ethylene effect—produce only relatively small differences in the illuminating duty with the Welsbach burner.

The explanation of such a remarkable fact is to be found in the peculiar conditions of combustion in the Bunsen burner. The gas, as is well known, prior to its combustion has added to it in the mixing-tube of the Bunsen burner a quantity of air insufficient to effect its complete combustion. But, on the other hand, there is sufficient to bring about complete disillumination of the flame. As soon as this mixture of gas and air, issuing from the tube of the burner, is brought to the temperature of ignition by the hot flame which encompasses it, incomplete combustion ensues, and, in a measure, combustion of air in an excess of gas. This is what happens in the inner green cone of the flame. By this means almost all the so-called heavy hydrocarbons are decomposed and partially burnt; and the products of the incomplete combustion, in addition to carbonic acid and steam, are carbonic oxide and hydrogen, with residual portions of marsh gas (which is only decomposed and burnt with difficulty), and a little acetylene. The hot gases which issue from the green cone of the flame of the Bunsen burner on to the interior of the mantle consist in all cases essentially of carbonic oxide and hydrogen, whether either rich or poor illuminating gas is used. These gases are burnt in the outer zone of flame which is delimited by the meshes of the mantle, by means of air which enters from outside it. They thus yield carbonic acid and water vapour; and

the combustion raises the meshes of the mantle to an intense white incandescence. The combustion around the mantle thus is with all gases—even of very diverse composition—essentially combustion of carbonic oxide and hydrogen. Thus, it is evident that the duty afforded by the mantles is affected only to a comparatively small degree by changes in the composition of the gas used.

Bearing in mind that the incandescent gas-light owes its illuminating power and brilliancy entirely to the high temperature of the flame, the grounds on which the properties of illuminating gas are estimated, and the methods used in its manufacture, must be modified, because since the introduction of the Welsbach light the production of light has resolved itself simply into a question of heating.

225. (2) *Gas as a Fuel for Cooking and Heating Stoves.*

—What is required here is gas of a high calorific power, providing the stoves are made suitably for economical combustion. In heating stoves the development of a high flame heat is important, because the efficiency depends to a great extent upon radiant heat by flame contact. (See par. 258a.)

226. (3) *Gas as a Fuel for Heating Water (Geysers).*—

This is an enormous field for the extension of the use of gas, and is covered at present to only a small extent. What is required of the gas for this purpose is a high calorific power; what is required of the apparatus is (a) the complete absorption of all the developed heat, (b) the complete removal of all the products which should be cold if (a) is satisfied. It is because these two conditions are not fulfilled in apparatus as made at present that this method of utilising gas is not as economical as it might be, and, unless special precautions are taken, dangerous. (See par. 258a.)

227. (4) *Gas as a Fuel for Gas Engines.*—A knowledge of the illuminating power of gas used for this purpose is useless, unless it constitute a guide to the calorific power. The efficiency of a gas engine depends upon the economical development of explosion-energy, together with the conser-

vation and utilisation of the heat of combustion, and it has been found that with gases of poor calorific value, the theoretical mixture required to produce the highest thermal efficiency, can be approached more nearly than with a gas of a high calorific power. The greater part of the heat expended in a gas engine is lost, being carried away in the exhaust, absorbed by the jacket and lost by radiation in the proportions of about 40 per cent. and about 30 per cent., only about 20 per cent. to 25 per cent. of the heat being utilised as work. The thermal efficiency and economy of gas engines vary with their size and adjustment; the highest result has been obtained from a 600 horse-power engine working with producer or power gas. Many tests of a public nature have been made upon gas engines; for instance, the Society of Arts trials, Professor Kennedy's tests, the tests made for the Institution of Mechanical Engineers and reported by Prof. F. W. Burstall; the tests made by Mr. Herbert A. Humphrey (see Proceedings Inst. Mech. E., January, 1901), and these can be consulted with advantage, as also can Mr. Bryan Donkin's book on Gas Engines, also the recently-published work by M. Aimé Witz. The writer has not seen comparable records of tests made upon the same type of engine and under the same conditions, but with the calorific power of the gas varied. A series of such comparative figures would be of great use to gas managers as enabling them to adjust the engines for the efficient and economical working of which they may be responsible. It is in this connection that the utility of the comparison of the calorific power of fuel carbonised and gas and products formed (see par. 222) will be seen, because if this were done, the thermal efficiency of a gas engine can be expressed directly in terms of the coal originally carbonised. With the advent of Mond gas the importance of gas engine testing will be evident at once. (See note on Mond gas, par. 285 *et seq.*) *Care should be*

taken in making comparisons that the figures are reduced to common units, as pointed out in paragraph 230.

228. (5) *Gas as an Open Flame Illuminant.*—A large percentage of gas supplied being still for use in luminous burners, and statutory tests being photometrical ones, it follows that illuminating power cannot be disregarded, and therefore in investigating the means which will enable us to know *how to produce gas of a given calorific power* the question of its illuminating power and the extent of parallel must always be before us. In making comparative tests of illuminating power for the purposes outlined in this chapter, and in studying recorded results, care must be taken that suitable burners are used for the various gases tested, and due allowance must be made in comparing records, for the neglect of this necessary precaution. It must be understood that the 24-hole Argand is adopted for testing 16-candle coal gas (or thereabout) enriched with cannel, on the basis of a *certain fixed developing efficiency in the burner*, this particular burner developing to its greatest extent the illuminating power of such gas (mantle illumination being put on one side). It stands to reason, therefore, that if tests are to be made upon other methods of enrichment, the point of comparison being *cost per candle power*, very grave errors will occur and very elusive results will be obtained if the most suitable burners for the candle power to be tested or for the method of enrichment (as, say, water gas enrichment) are not used. There have been of late years many exhaustive records of comparisons of different methods of enrichment, but after careful perusal they appear to the writer to be quite vitiated (as comparisons) by the neglect of this important precaution. *Care should be taken in making comparisons as to illuminating power that the figures are reduced to common units. The comparative table of standards of light at the end of chapter 3 will enable this to be done.*

229. The intending investigator on the lines laid down in paragraphs 221 and 222 will do well to make himself acquainted with the work that has been done on this very interesting and important matter of calorific power. The file of the "Journal of Gas Lighting" seems to afford the best information in this direction, and the articles and reports upon the questions of Water Gas, Gas Enrichment, Calorimetry and Gas Engine Testing might with advantage be consulted. It will be abundantly evident that the reason for different experimentalists' divergent results is because each operator has been necessarily limited to the investigation of the gas, the making or testing of which has come under his personal notice. It necessarily follows that different series of tests yield different results and cause different conclusions, which can only be utilised in its particular area or district. Many experiments have been published, for example, in which a parallel is drawn between heating and lighting power, and various conclusions have been arrived at. One has only to examine for a moment the relative values for heating and lighting of, say, carburine and benzol (see appendix), and it will at once be clear why, without full data, such tables of results are decreased in value. Had each experimentalist given with his calorific results full details and all data on the points outlined in paragraph 222, we should by now be in a considerably further advanced condition of knowledge of the subject, and the writer therefore urges the importance of tests being made independently at as many gas works as possible.

230. The photometry of gas is dealt with in another part of this book, as is the photometry of enriching materials and also gas analysis. It remains to describe here a method of practically and accurately ascertaining the calorific power of gas. In studying records of calorific tests the first question that will occur is, "What is the unit employed and ex-

pressed?" There are various units of heat, and the following definitions and formulæ will enable different records to be compared and reduced to a common basis:

(a) *A Calorie* is the amount of heat required to raise 1 kilogramme (1 litre) of water 1 degree Centigrade (properly speaking, from 0° to 1° Centigrade). This calorie is properly called a *kilo-calorie*, as distinguished from a *gramme-calorie*, which is based upon the use as a unit of 1 gramme of water, and is one one-thousandth of the kilo-calorie.

(b) *A British Thermal Unit (B. T. U.)* is the amount of heat required to raise 1 pound of water 1 degree Fahrenheit.

(c) *Calories per cubic foot* are the number of kilogrammes (litres) of water which can be raised through 1 degree Centigrade by the complete combustion of 1 cubic foot of gas, corrected in volume to normal temperature and atmospheric pressure. *When we refer to "calories" in technical tests of gas, we mean "calories per cubic foot."*

(d) *Calories per cubic metre* are the number of kilogrammes (litres) of water which can be raised as above, but by 1 cubic metre of gas. Calorific tests in countries where the metric system prevails are expressed in *calories per cubic metre*.

(e) *B. T. U.'s per cubic foot* are the number of pounds of water which can be raised through 1 degree Fahrenheit by the complete combustion of 1 cubic foot of gas, corrected in volume to normal temperature and atmospheric pressure. *We usually use this formula in this country:*

(f) To convert *calories per cubic foot* into *B. T. U.'s per cubic foot*, multiply by 3.97 (3.968).

To convert *calories per cubic foot* into *calories per cubic metre*, multiply by 35.316.

To convert *B. T. U.'s per cubic foot* into *calories per cubic metre*, multiply by 8.9.

(g) *Specific Heat*.—Different bodies require different quantities of heat to effect in them the same change of temperature. This capacity of a body for heat is termed its "specific heat," and may be defined as being the number of units of heat necessary to raise the temperature of a body 1 degree (independently of the unit of volume or

mass and the scale of temperature). *Water is taken as being the unit (= 1) of comparison.* Specific heat varies with the temperature to a slight extent. This variation need only be taken into account when scientific investigations of extreme accuracy are being made.

(h) *Latent Heat.*—When a body passes from one state to another it absorbs or parts with a large amount of heat without changing its temperature, the heat thus absorbed being unindicated by the thermometer.

The latent heat of liquefaction expresses the number of heat units (independently of the unit of volume or mass and thermometer scale) thus absorbed or parted with in passing from the solid to the liquid form.

The latent heat of vapourisation expresses the number of heat units (independently, as above) thus absorbed or parted with in passing from the liquid to the gaseous form.

(k) *The latent heat of steam*, which concerns us here, as will presently be explained (see par. 247), is 967° Fahrenheit, or 537° Centigrade at 212° and 100° respectively (namely, the temperature at which water passes to steam).

The above definitions are given here, as most of them will be frequently referred to in the following paragraphs.

231. Until comparatively recently the method of ascertaining the calorific power of gas was an operation more or less difficult to perform, and chiefly suitable for laboratory use. A short description of some of the methods employed is given below, while the calorific power can also be determined from chemical composition. The little-noticed work of F. W. Hartley has proved to be the foundation of modern calorimetry as it affects gas-makers, the indirect result of his work being that it is now possible to investigate technically and at the same time accurately the heating power of gaseous and liquid fuels.

232. *Favre and Silbermann* were among the first experimentalists to accurately determine calorific powers by means of a calorimeter. They used a combustion chamber immersed in a calorimeter chamber or water bath, and arranged for

the introduction of an oxygen jet (to support combustion) and for the passing away of the waste gases during combustion. In instruments of this (the constant pressure) type complete combustion does not take place, and as the combustion occurs at atmospheric pressure, the products being led away, some of the hydrogen and carbon present in the fuel escape as waste gases. They are therefore arrested, passed through an organic analysis apparatus, and being thus determined as hydrogen and carbon, their heat value is taken according to known coefficients, as is also the heat value of the carbon and cinders remaining after the incomplete combustion. These are then added to the figure ascertained from the rise in temperature of the water in the calorimeter bath, to which must also be added the coefficient for the apparatus itself, based upon the specific heat of its constituent materials. The sum of these represents, subject to certain corrections, the calorific power of the fuel under examination. Alexejew, Fischer, Carpenter, Barrus, Schwackhöfer and others have produced calorimeters which, while comprising details of ingenuity, can be mentioned here as being modifications of the Favre and Silbermann instrument. They are used for the accurate determination of heat value of solid fuels. The Lewis Thompson apparatus described in chapter 6 is generally used for technical tests of solid fuels in this country.

233. *Berthelot* produced the well-known calorimetric bomb, in which combustion takes place at constant volume, and which has been greatly used for the laboratory determination of solid and gaseous fuels. The apparatus consists of a platinum bomb capable of resisting high pressure, the bomb being sealed and provided with an arrangement by which oxygen can be introduced at high pressure, a perfect combustion taking place on the production of an electric ignition. The calorific power is calculated from the heat im-

parted to a water bath, corrections of the most precise character being made. The chief instruments of this type are those of Mahler, Andrews, Atwater, Kroeker, Hempel, and Witz, the combustion always being ascertained at constant volume, requiring correction for constant pressure. Berthelot's "Essai de Mécanique Chimique" might with advantage be consulted, while a very useful *précis* will be found in H. Poole's "Calorific Power of Fuels" (Chapman and Hall).

234. Hartley's calorimeter is the one which forms the basis of the Junker, the Dowson, and the Simmance-Abady calorimeters, and, since it is with these forms that gas works tests are made, the description of the calorimeter which Mr. Hartley produced is given at length. The general principle of these calorimeters can be enunciated here as being that laid down by Mr. Hartley in 1884—*calorific effect being directly calculated from the rise in temperature of an ascertained flow of water, due to the combustion of a measured quantity of fuel*. The calorimeter was produced in 1884 before the "British Association of Gas Managers," the following being a description of its construction and method of use:

235. "From a small cistern water flows over a sensitive thermometer, thence through pipe connections into a case surrounding the stem of a suitable burner, onward to a metal casing, or jacket, enveloping the calorimeter, then makes its way to the upper part of the latter, descends, after traversing a series of shelves which present a very large surface, and finally passes out to a collecting tank at the base of the instrument. The burner is passed upward into the centre of a cylindrical chamber at the bottom of the calorimeter; and, as already stated, the burner stem is surrounded by a casing through which the supply water flows. Loss by radiation from the burner is thus prevented. The gas is measured by a special meter, and its rate of consumption and the rate of water flow are *regulated* until the issuing water is found to be a few degrees

higher in temperature than that at which it enters; and the temperatures, as indicated by the four thermometers employed, are found to be steady. During these adjustments, water runs to waste through a bye-way cock."

236. "When all is ready, and with the meter index at zero, the bye-way cock is instantly turned, and the passage of the outflowing water diverted to a collecting tank. The quantity of gas usually burned per experiment is one-quarter cubic foot, and the time occupied with ordinary coal gas 10 to 12 minutes. During the experiment, the temperatures of the inlet and outlet water should be frequently observed, and now and then also the temperature of the jacket. When the desired quantity of gas has been burned, the water flow is promptly turned to waste. The collected water is next measured, and its weight calculated or, better, weighed directly. The weight in pounds, multiplied by the number of degrees the water has been raised, gives the heating power due to the quantity of gas burned. Thus, if 20 pounds of water have been raised 8° Fahrenheit by one-quarter cubic foot of gas, we have $20 \times 8 = 160$ pounds, Fahrenheit units, for one-quarter cubic foot, or 640 for 1 cubic foot. Two or three trifling corrections have to be made upon observed results, but they are of the simplest nature.

"The products of combustion are so completely reduced to the temperature of the inflowing water that, without aspiration, they would not rise through the instrument. The aspirator is simply a copper chimney, heated at its upper part by a ring gas-burner.

"With this apparatus the operations are simple and easy, while the results are accurate. The indicated power for pure hydrogen agreed very closely with that found by the most eminent scientific authorities—namely, more than 62,000 pounds of water raised 1 degree Fahrenheit, or 34,445 pounds of water raised 1 degree Centigrade."

237. *The Simmance-Abady Calorimeter* is avowedly based upon the above, but is of a simpler form. The Junker and the Dowson are both similar, and if the writer describes the one in the devising of which he had a modest share it is because his experiments with the two former proved the need of an instrument which should be still simpler, easier of

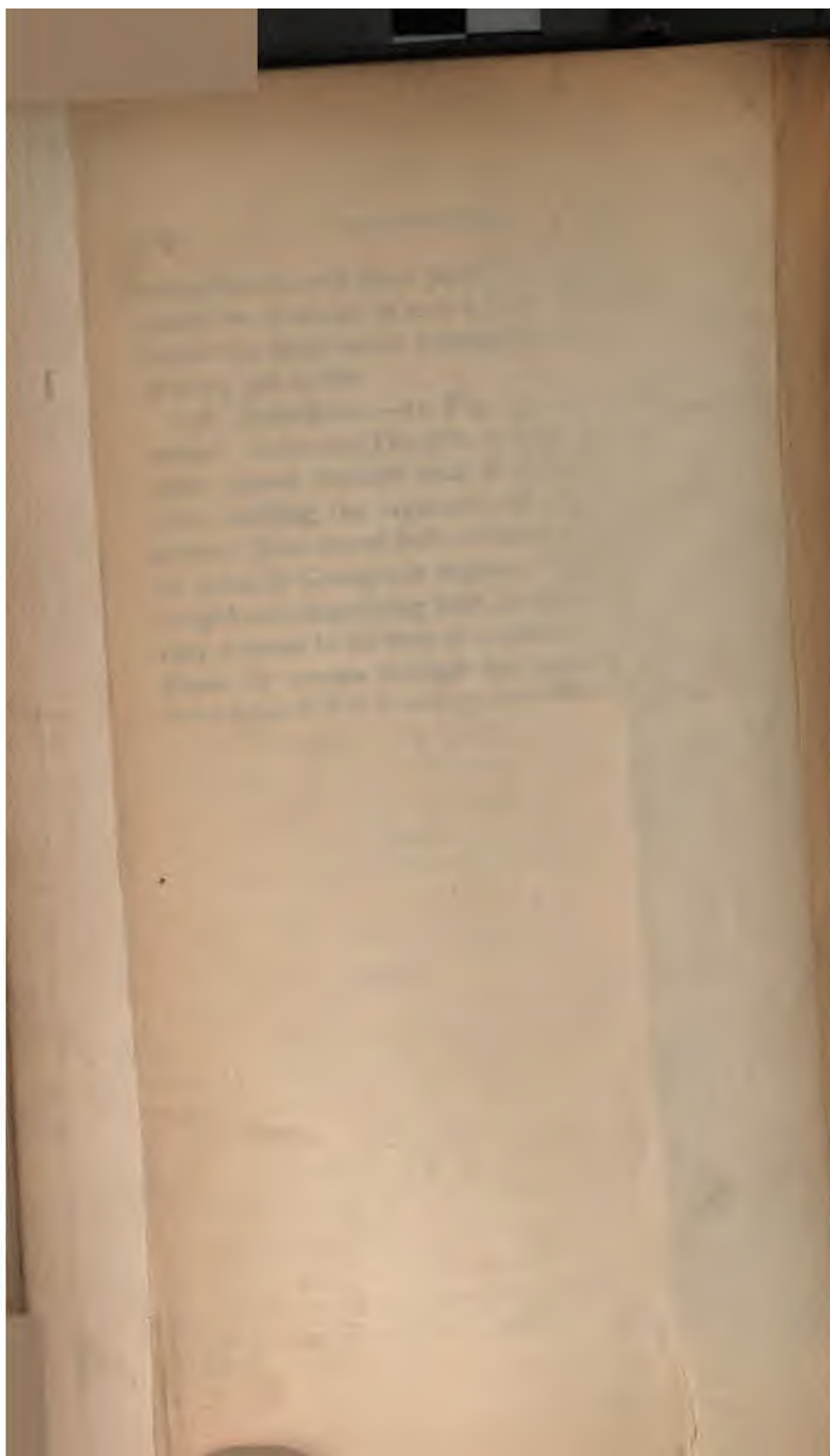
manipulation, and more perfectly under control, and which should be produced in such a form and at such a price as to render the calorimetric testing of gas possible of attainment in every gas works.

238. *Description.*—In Fig. 37 the calorimeter is represented. In section, Fig. 37a, A is the water inlet, whence the water passes through cock B and fills water-level tube C (for enabling the regularity of pressure to be seen at a glance), flows round bulb of thermometer D (the thermometer being in Centigrade degrees, divided into tenths and arranged in a magnifying tube, to enable the height of the mercury column to be seen at a glance), and along the course shown by arrows through the annular chambers E E E E, down tubes F F F F, and up through tubes G G past the baffle plate into upper receptacle H, round bulb of thermometer J, which is similar to thermometer D, and thence by outlet K. The heated water is discharged by waste L, or by turn of cock or tilt of bucket, into graduated measure M, which is a measure subdivided into 2 c.c. and having a capacity of about 1000 c.c.

239. The products of combustion rise up centre shaft N, and, partially condensing in chamber O, drop down annular passage P P P P and issue (being reduced to the temperature of the original fuel), which should be the same as the inlet water and approximate to the air of the room) as CO₂, non-condensable products and water, at lip Q. A shutter is provided by which the flow of the products, and therefore their temperature at point of issue, can be regulated and seen on thermometer provided for the purpose.

The condensed water is collected in graduated measure R for purpose of the deduction to be made upon gross results (see par. 247). S is the Bunsen burner for burning gaseous fuels, a special lamp and balance being provided for liquid fuels.





To Fit Up Calorimeter.—The stand is placed on a level base and the calorimeter is stood upon it, with inlet cock conveniently to the water supply. The two thermometers are slipped carefully (being wetted) in the rubber bungs already placed in the sockets *D* and *E*, the glass tube being put into the remaining socket. The two thermometers and water-level tube thus stand side by side, and the observation of their indications is thus facilitated.

The correct and rapid observation of the inlet and outlet thermometers and of the water-level is, as will be seen later, a most important point. The thermometers should be carefully tested, and any slight difference in their readings under like conditions noted. They indicate in tenths of a degree Centigrade, and are very sensitive; they require careful handling, and once in their places should not be disturbed. The inlet cock is connected to the water supply which should be such as to provide a constant head (see par. 57). The outlet *L* is connected by a length of rubber tube to a convenient waste service. The burner is connected by a rubber tube to a gas supply, which should be such as to give a constant pressure (see par. 245). The gas has to be measured by an experimental meter, which should be in a position as to be easily read by an operator working at the water outlet of calorimeter (see par. 245). The inlet thermometer is placed in the rubber bung at the inlet. The proper appreciation of the readings on this thermometer is important (see par. 254). The small glass thermometer is placed at the products outlet. The large glass thermometer is placed at the water outlet of calorimeter.

To Test Calorimeter.—Turn on the water gently until it rises almost to the top of the glass tube, while it is going to waste at the outlet of calorimeter. Close the top of the glass tube, increase the water flow and let it so run for two minutes. *This is only necessary when the calo-*

rimeter is first fitted up. See that all joints are sound, and then unstop the glass tube and reduce the water flow until it stands at about half way up the tube. Mark the meniscus by a rubber ring slipped round the glass tube.

242. *To Make a Test.*—Observe the water-level and see that it is constant. *If the water supply varies the water-level in tube will vary. If an accurate test is required it should remain at the observed point.* Light gas burner outside calorimeter, put it under calorimeter and lift it until the stand can be slid beneath it. See that the burner rests in the space prepared, when it will be central with the central shaft N. A small mirror will enable operator to see how flame is burning. Let gas burn (having adjusted its rate and being assured of its regularity), and let water run until the outlet water thermometer, which will have risen as the water has absorbed the heat, has again become constant. Adjust the products outlet door until the temperature of the issuing products is the same as the inlet water. Observe the temperature of the gas and of the atmosphere. *The operator should endeavour to work under such conditions that the temperature of atmosphere, gas, and inlet water approximate.* Observe also the reading of barometer. Having effected the adjustment of the products outlet, watch both the water thermometers for a few seconds, see they are constant, and *note the difference*, adding or deducting any observed difference in thermometers when tested as described in par. 240.

243. As the meter hand (an ordinary Photometer meter is assumed) passes a division, say zero, turn the outlet water, which has been running to waste, into the tall cubic centimetre measure, and as the meter hand passes a second marked division (say 12) switch water back to waste. Read on scale of glass measure quantity of water run in the interval. Repeat the operation (which will take a few seconds

only) twice, and take the mean of the three readings. The tall measure is emptied for each reading.

244. The known data will then be:

- (a) Difference in temperature of inlet and outlet water.
- (b) Quantity of gas passed (mean of three readings).
- (c) Quantity of water heated (mean of three readings).

Say the figures are:

Gas burned, 12 divisions (six hundredths of a cubic foot).

Water heated, 362 cubic centimetres.

Difference in temperature, $21.7^{\circ} - 12.5^{\circ} = 9.2^{\circ}$.

Refer to calorific tables (Appendix L).

Take 12 in top line, 362 in left-hand column, and note converging figure, 18.1, which multiply by 9.2.

$18.1 \times 9.2 = 166.52$ calories per cubic foot, gross,
or, $166.52 \times 3.97 = 661.08$ B.T.U. " " " "

The conversion from calories to B. T. U. is made here, for example, but it is advisable not to do this until after the reduction to *net* results has been made. It should also be stated that 4, instead of 3.97, is often used as the factor for conversion.

The above result is the *gross* result, the gas not being corrected for volume by tabular number, and no deduction being made for the *latent heat of steam*.

The correction of volume of gas is made as in a photometrical test, and for the same reason. The writer does not think, however, that this correction has been made in most of the available records of calorific tests; but it certainly should and can easily be made.

The correction for latent heat of steam, converting the results from *gross* to *net*, is explained in pars. 247 and 248. It will be convenient here to explain the—

245. *Calorific Tables*.—These have been calculated in order to save the time of experimentalists, and are based, firstly, on the use of Centigrade thermometers; secondly, on the measurement of water in fractions of a litre; thirdly, on the use of an ordinary experimental meter (see Appendix

L). It will be observed that the gas measurements are given as "divisions of ordinary experimental meter." The reason for this is because in many cases it will be found possible, and in all cases desirable, to use the meter on the Photometer, connecting the burner of calorimeter from a special cock on the Standard burner pillar. By this means a perfectly governed gas service is used. A small table can be stood by the Photometer and a calorific test made immediately after an illuminating-power test. Now most experimental meters and all Photometer meters are arranged for one-minute observations (and are, therefore, of $\frac{1}{12}$ th cubic foot capacity per revolution, reading to $\frac{1}{600}$ th cubic foot for each small division with the "hourly rate" hand). The tables are calculated on the basis of 6, 10, 12, 15, 20, or 24 of these divisions being used, and the calculation of gross calorific power is thereby reduced to a minimum.

It will be found convenient to mark the dial with ink or slips of paper at the various divisions from zero shown in tables, namely, 6, 10, 12, 15, 20, 24, and use any convenient interval as the standard amount. Thus, if a very small quantity of gas is being used, six divisions will give a good reading; but if the meter hand is travelling rapidly, a longer space should be allowed.

A clock-meter should on no account be used—the indications being obtained through gear are not sufficiently accurate.

246. If the Calorific Tables are not available, the result (uncorrected for gas volume and latent heat of steam) is calculated as follows:

$$\left(\frac{n}{m}\right)t = \text{gross calories per cubic foot,}$$

where n = fraction of a litre of water heated,
 m = quantity of gas in cubic feet burned,
 t = difference in readings of inlet and outlet thermometers in Centigrade degrees.

247. *Correction for Latent Heat of Steam.*—In the combustion of gas a certain amount of heat generated is, for general purposes, non-effective, being due to the combustion of the hydrogen in the gas which escapes as steam with the products of combustion. In a calorimeter, however, this steam is condensed into water, and as it gives up its latent heat to the circulating water a deduction, based on the amount of condensed products thrown down, is made. The condensed products are collected in the small cubic centimetre measure, which shows $\frac{1}{10}$ th of cubic centimetre, the quantity of gas whose combustion gave off the amount collected being measured and noted. Now the latent heat of steam, as explained in par. 230, is 537° , and if the water in the calorimeter were only converted from 100° to steam and *vice versa*, then 537 calories would have been absorbed for every kilogramme (1000 c.c.) of condensed products. In actual practice the water has to be raised to 100° before being vaporised, and, as it is known that the heat necessary to raise water from a low temperature and then evaporate it is nearly constant, we must add to the figure “537” the number of degrees through which the water has been raised. It will be, as a rule, about 60° Centigrade, and so it is reckoned in practice that for every kilogramme (1000 c.c.) of condensed products collected per cubic foot of gas (for this is the unit volume of gas in which results are expressed, *i.e.*, “calories per cubic foot”) 600 calories have been absorbed, 600 being sufficiently near to 597 ($537^{\circ} + 60^{\circ}$). Since the condensed products are measured as cubic centimetres, and since 1 cubic centimetre is $\frac{1}{1000}$ th part of a kilogramme, it is obvious that

(a) *For every cubic centimetre of condensed products collected per cubic foot of gas burned, a deduction from the gross calories per cubic foot, of .6 calorie must be made.*

It is often the practice to convert "*gross calories per cubic foot*" into "*gross B. T. U. per cubic foot*" by multiplying the former by 3.97 (see par. 230 [f]). In such a case, and assuming the measurement of condensed products collected to be in cubic centimetres, the rule is:

(b) *For every cubic centimetre of condensed products collected per cubic foot of gas burned, a deduction from the gross B.T.U.'s per cubic foot, of 2.382 B.T.U. must be made ($3.97 \times .6$).*

248. The direct calculation as above from 1 cubic foot involves the burning of and collecting the products from that volume, while the water is running through the calorimeter, as when a test is being made. It will be found more convenient to observe the amount during two or three revolutions of the meter hand and make a corresponding deduction. For instance, take the example given in paragraph 244, in which the gross calories per cubic foot were 166.52 and the gross B. T. U.'s per cubic foot were 661.08, and assume that three tests of $\frac{1}{3}$ th cubic foot of gas were made. Assume that the products were collected during these three short tests, and were 2 c.c., 3 c.c., and 4 c.c., respectively. The mean is 3 c.c. for $\frac{1}{3}$ th cubic foot, which is equivalent to 12×3 c.c. for 1 cubic foot = 36 c.c. per cubic foot. Applying the rule (a) as above, the deduction to be made is $36 \times 0.6 = 21.6$ calories, reducing the gross of 166.52 to 144.92 calories per cubic foot net. Applying the rule (b) as above, the deduction to be made is $36 \times 2.382 = 85.752$ B. T. U.'s, reducing the gross of 661.08 to 575.328 B. T. U.'s per cubic foot net.

249. To sum up paragraphs 242 to 248, the explanations can be separated from the rules for testing which are here recapitulated :

- a. Take differences in temperature of inlet and outlet water.
- β . Read quantity of gas passed.

- γ. Read quantity of water heated.
- δ. Refer to calorific tables, and
- ε. Multiply the figure found by α.
- ζ. Collect and measure products condensed from a measured volume of gas.
- η. Convert this into calories (each cubic centimetre per cubic foot being multiplied by 0.6), and deduct from result given by ε.
- θ. Divide result by tabular number.
- κ. Convert, if desired, to B. T. U.'s, etc., by rules (par. 230 [f]).

250. If accurate tests are desired, the following points must be observed :

- 1. A constant head of water at an approximately constant temperature.
- 2. A properly governed gas service with an accurate central-dial, wet, experimental meter.
- 3. Well-drained measures before making tests.
- 4. The approximation of the atmosphere, gas, and inlet water temperatures.
- 5. The regulation of the outlet products' temperature to this figure, if possible; and, if not, to that of the inlet water as taken in the calorimeter.

251. *Junker and Dowson* have both produced calorimeters based upon Hartley's, the former being a good instrument and the latter being badly designed, that is to say, it does not provide the central flue, which appears to the writer to be necessary in order to obtain anything like an equal absorption of heat by the water. To those who are tolerably familiar with this class of calorimeter a consideration of the following points will show in what lies the advantages of the Simmance-Abady instrument described above.

252. *Short, Rapid Tests.*—By its means a succession of short tests can be made, and if any variation of temperature occurs (which with this apparatus and the method described is unlikely), such test can be disregarded and another made, each testing taking only a few seconds.

An endeavour has been made in the apparatus and in the instructions and tables to eliminate the chances of error which occur when a long test is made with a large quantity of water, such as two litres, and upon the mean of varying thermometer readings. It is apparent that, unless the experimenter can time absolutely the duration of each separate temperature and apportion the gas and water to each, a mean reading will be misleading. The variations in temperature are mostly caused by inaccurate construction of the calorimeter or want of proportion between amount of gas burned and capacity of instrument.

253. *Constant Tests.*—By the elimination of unnecessary details the operation of testing is a simple matter, and it is possible for a gas manager to keep the calorimeter constantly at work (as he does a Jet Photometer) and at any time, by the expenditure of less than a minute, to ascertain the calorific power of gas.

254. *Facilities for Adjusting Rate of Products.*—The calorimeter has been constructed so as to present a large surface of water chamber for the absorption of the heat from the combustion at the burner. At the same time the area is made sufficiently large to allow the combustion of varying quantities of gas, the areas of the up-shaft and down-cast flue being apportioned so as to allow the proper adjustment of the products outlet whatever the size of flame or rate of gas consumption (increasing or reducing their rate of egress until complete heat absorption and reduction to inlet water temperature has taken place). This is an important point, because, unless a parallel ratio between inlet water and outlet products temperature obtains in all experiments, the value of a result is greatly lessened. A concrete example will show the uselessness of results recorded without this condition obtaining. Suppose two different gases are being calorimetered, one being burned at 8 feet an hour and the other at

5 feet, and suppose the products outlet is not adjusted and the difference in temperature between inlet water and outlet products was in one case 5° and in the other 0.5° . It follows that the calculated results of the two tests are in no way comparable, *since in one case some of the heat of combustion has escaped, and in the other case practically all of the heat has been absorbed by the water, thus increasing its temperature.* The writer knows of no other calorimeter than the one illustrated in Fig. 37, in which this most important adjustment can be made efficiently.

255. *Accurate Observation of Temperatures.*—The importance of having sensitive and easily-read thermometers is recognised for the first time in the Simmance-Abady instrument. The thermometers are made with magnifying scales and are placed side by side, and, the scales being open and indicating to $\frac{1}{10}$ th degree Centigrade, the slightest variation can be instantly detected; both thermometers are under observation at the same time, as it has been found very difficult, with the thermometers placed as they are in other calorimeters, to read them accurately.

256. Owing to the importance of preventing *loss of heat by radiation*, or absorption of atmospheric heat by the apparatus, it has been found essential to properly jacket the calorimeter, and so a water-jacket is provided, and the outer wall of this may be packed and lagged with wood. The calorimeter is also constructed so that there is not only a complete, but also a gradual, absorption of heat by the water chambers, and, owing to these points having been regarded, it has been found an easy matter to obtain results which are absolutely concordant.

257. *Constant Water Supply.*—The above paragraphs point out the difference between the Simmance-Abady and the Junker and Dowson calorimeters. Whatever calorimeter is used, however, it is equally essential that there

shall be a constant water supply, both as to pressure and temperature. It will at once be seen that, if the rate at which the water passes through or the temperature at which the water passes into the calorimeter is continually variable, there will be a very great difficulty in getting constant readings of the thermometers. The so-called constant-level funnels are of little or no use, because they are subject to variations if the main supply varies and the extent of the variation cannot be observed. What is recommended, therefore, is, firstly, a means of observing if the level is constant (as in the glass tube of the Simmance-Abady instrument); secondly, a small tank or cistern placed in the laboratory and provided with a ball valve. If this latter is available little trouble will be found either in rate of flow or temperature at inlet, but if special circumstances should call for special arrangements, then an arrangement which the writer has used himself, viz., a specially designed constant-level cistern, based on Mariotte's bottle, can be used.

258. Finally, it will be found advisable to use the following form and fill in as many of the records as possible, and by that means results which will be valuable for comparison and for the purposes outlined in the beginning of this chapter will be obtained. The Lewis-Thompson method of testing calorific power of a solid fuel is described in the chapter on coal. The use of the Simmance-Abady calorimeter in testing liquid fuel is described in the chapter on enriching materials.

Testing the Actual Efficiency of Stoves, Gas Engines, etc.

258a. The writer advises in paragraph 222 (e) "a comparison of the effective results in actual ordinary use yielded by gases of varying qualities." It must always be the desire of the gas-maker to place at the disposal of the users of his

Fig. 38.
FORM FOR RECORDING CALORIFIC TESTS OF GAS.
DATA FOR TESTS PROPER.

Short Test	Gas Burned	Temperatures of Water		Water Heated	Differences of Temperature		Number in Caloric Tables	Gross Result in Calories per Cu. Ft.	Condensed Products Collected	Gas Burned in "Products" Test	Deduction in Calories for Latent Heat	Net Results	
		Inlet	Outlet									Calories per Cu. Ft.	B. T. U. per Cu. Ft.
1st	10 div.	15.5° C.	26° C.	300 c.c.	10.5	10.5 mean	17.88	17.88 X 10.5	3	Cu. Ft. 1½	5 X 12 X 0.6	186.74-36	155.2 X 3.97
2d	10 div.	15° C.	25.6° C.	296 c.c.	10.6		17.88	or	5	1½	36	.971 (Tab.) say, 155.2 calories	616.614 B. T. U.
3d	10 div.	15.3° C.	25.7° C.	298 c.c.	10.4			186.74	7	1½			

OTHER NECESSARY DATA.

Date	Time	Experi- mentalist and Appa- ratus	Temperatures			Tabular No. from Gas and Barometer	Rate of Gas per Hour	Rate of Water per Hour	Illumi- nating Power	Hydro- carbon Vapors	Analysis of Gas in Percentages				
			Gas	Prod- uct	Air						CO₂	Heavy Hydro- carbon	Oxy- gen	CO	C/H₄
Mch. 28, '01	3.30	Jones S. & A.	58° F.	59° F.	60° F.	.971	5½ ft.	100 litres	16.2 candle	0.1	1.32	4.1	0.5	5.6	39.24
															47.03
															2.11

Notes as to Make of Gas.

Kind of coal.

Temperatures of condensation.

When made.

Percentage of enrichment.

How made, scrubbed, washed, etc. Where stored.

How enriched.

What result with incandescent burners, etc.

NOTE.—The figures in this example are not a record of actual test, but they are possible figures. If it is not possible to obtain all the data, as many as possible should be recorded.

product the form of apparatus best adapted to his particular gas for incandescent lighting, cooking and heating, water heating and gas-engine fuel. Given the thorough knowledge of the calorific power of his gas which the tests recommended above will yield, it is no difficult matter for the gas-maker to test the actual effectiveness of cooking and heating stoves, water heating apparatus and gas engines, and to adjust those placed in his district so that the result given will approximate closely to and compare favourably with the theoretical yield. It stands to reason that a gas stove supplied broadcast cannot yield its best result for, say, both 14 and 17 candle gas without adjustment for one or the other. It is indisputable that with the increase of central power stations, of generator gas plants, and the advent of Mond gas, and moreover with the increased efforts of those responsible for electric light undertakings, the gas-maker cannot afford to leave a stone unturned to utilise to the fullest extent the convenient and useful fuel for which he is responsible; or in other words, to give his customers not only the best gas for their money, but also the best apparatus for their gas. The means of testing different forms of stoves, water heaters, engines, etc., will naturally have to be adapted to suit each particular case, and must be left to individual initiative; but if any suggestions from the writer will be of service at any time they will be willingly placed at the disposal of all interested correspondents.

Specific Gravity.

259. A knowledge of specific gravity is very useful to the gas-maker when it is desired to ascertain the weight of gas produced from any sample of coal. It also serves, though to a very limited extent, as an index to illuminating power; but this is not a use to which it would be put, as the ratio of

the two is so very indefinite, and an admixture of an enriching material quite upsets any parallel there may be. Another use to which it is put is in connection with the flow of gas in pipes, as the following shows :

260. Let Q = quantity of gas in cubic feet per hour,
 l = length of a pipe in yards,
 d = diameter of a pipe in inches,
 h = pressure, in inches, of water,
 s = specific gravity of gas (air being equal to 1).

Then (a), if it be required to find the number of cubic feet of gas of a given specific gravity which will flow in one hour through a pipe of a given length and diameter and at a given pressure, the following is the formula :

$$Q = 1350 d^2 \sqrt{\frac{h d}{s l}}.$$

(b) If it be required to find the pressure, in inches, of water required to discharge in one hour a given number of cubic feet of gas of a given specific gravity through a pipe of given diameter and length, the following is the formula :

$$h = \frac{Q^2 s l}{(1350)^2 d^5}.$$

(c) If the diameter of a pipe is required which will enable a given number of cubic feet of gas of a given specific gravity to pass through a given distance at a given pressure, the following is the formula :

$$d = \sqrt[5]{\frac{Q^2 s l}{(1350)^2 h}}.$$

(d) Having ascertained the quantity of gas at one gravity, and it being required to find the quantity (as in (a)) of gas of another gravity, the following is the formula :

$$Q = \frac{q \times \sqrt{s}}{\sqrt{x}}.$$

where Q is quantity required to be found, and x the new gravity.

It is thus demonstrated that the specific gravity of a gas is a necessity to any of the calculations mentioned above.

261. To find the specific gravity of any gas with scientific exactness a very accurate and sensitive balance must be employed, as well as two glass globes, of equal weight and as nearly of equal size as possible, one being used to contain the air and the gas which are to be weighed, and the other as a counterpoise. Many precautions have to be taken, and great skill in manipulation is necessary. The true specific gravity of a gas is the relative weight of any volume in a *dry* state to the weight of an equal volume of *dry* atmospheric air. This is, in a scientific way, frequently determined by weighing a globe charged with dry air, and afterwards when charged with dry gas—the water vapour in the air and gas being removed on their way to the globe by slow delivery through a long tube containing dry chloride of calcium. Corrections can, however, be made by calculations which, as usually set forth, are somewhat troublesome, involving as they do considerations of aqueous tension, the volume and the weight of vapour, and the subtraction of the latter two from the volume and weight of the contained gas.

262. Mr. Greville Williams, F.R.S., whose careful researches in many directions are well known, has described in detail his method of making a precise determination of specific gravity, which he communicated to the Gas Institute in 1882, and which description is given in pars. 275 *et seq.*

263. Such extreme accuracy is, however, rarely needed for ordinary purposes, and in most cases it is sufficient to know the relation in gravity which coal-gas, containing water vapour (as gas and air do under usual conditions), bears to air also containing such vapour. The quantity of water vapour in the air, or in any gas exposed to water, varies with the temperature, but is constant for each degree, while it is independent of the kind of gas. Thus, under the

conditions stated, any volume of coal-gas will, at any given temperature, contain as much water vapour as is contained in an equal volume of air of the same temperature.

264. The specific gravity of moist gas may be readily found by means of Schilling's effusion test, which is a modification of Bunsen's instrument. It consists (Fig. 39) of a cylindrical glass vessel, within which is placed a glass tube, the latter surmounted by a metal cap, and its lower end fitted with a metal base, which serves as a foot and as a load to keep the tube immersed in water. The cap carries two cocks, one on the side and the other on a short upright pipe. The latter is a three-way cock, with a pointer and an index marked "vent," "off," and "on." The tube has two rings engraved upon it, one near to the base and the other near to the cap. The "vent" is through the plug of the cock, but when this is turned to "on" the only opening for air or gas is through a very thin disc of platinum, perforated with a minute hole, in the nozzle of the cock. The specific gravity is determined by ascertaining the time in seconds which equal volumes of air and of gas occupy in escaping from the minute orifice under equal pressures, and then dividing the square of the gas time by the square of the air time, being based on the fact that the times which equal volumes of different gases will occupy in issuing from a small (and the same) orifice, under constant pressure, or under equal pressures (the sum of which is constant), are in the ratios of the square roots of the densities.

265. The tube, being immersed in the tank, is charged with air by raising it and letting the air enter through a bye-way in the stop-cock. The cock is then closed and the tube re-immersed. Next the cock-plug is turned, so as to allow the air to escape through the hole in the disc. As soon as the water reaches the lower mark on the tube a stop-watch is started, and is afterward immediately stopped

when the water reaches the upper mark. The time in seconds is then noted. The tube is charged with gas in the same way, except that it enters through a flexible tube attached to a special cock provided. The operation of discharging is repeated. Let time for air be 180 seconds, and for gas 120 seconds. To find specific gravity square both numbers, and divide the smaller by the greater, thus:

$$32400 \div 14400 (= 0.44 \text{ sp. gr.})$$

Care must be taken to ensure the water in the apparatus



FIG. 39.
SCHILLING'S SPECIFIC
GRAVITY TEST.



FIG. 40.
LETHEBY SPECIFIC
GRAVITY GLOBE.

being of the same temperature as the air in the operating room, and at least two trials should be made with the air and with the gas.

266. A more refined method than Schilling's is that which was devised and used by the late Dr. Letheby, whose specific gravity globe is represented in Fig. 40. It has two necks,

each furnished with a small and light stop-cock, the upper one having screwed upon it a glass tube surmounted by a small gas-burner, and containing a sensitive thermometer. The weight of the globe with the cocks, but without the thermometer tube, in an exhausted state and when filled with moist air at 60° F. of temperature, and under 30 inches barometric pressure, are engraved upon the globe, or ascertained and recorded. The globe is charged with gas by being screwed upon the nose-piece of a gas-pillar, and the gas allowed to flow through and escape from the jet until all air is expelled; the lower cock is then closed, and (in order to avoid any greater pressure within the globe than that of the atmosphere) the upper cock is closed an instant later. The temperature indicated by the thermometer in the tube is at once noted, the tube removed, and the globe placed in the pan of a sensitive balance, a counterpoise weight equal to the weight of the globe in a vacuous condition being placed in the other pan of the balance, together with as many grains and parts of a grain as are needful to bring the balance into equipoise.

267. It is absolutely essential that the outside of the globe be dry, which cannot be the case when the weighing is effected in a moist atmosphere of higher temperature than the globe, owing to the inevitable condensation of some water vapour. Hence, the balance should be enclosed in a glazed case, in which should be placed a glass vessel containing two or three ounces of dry chloride of calcium, which absorbs moisture, and the globe should be allowed to rest in the balance pan, with the case closed, for some minutes before the final weighing is made.

268. Suppose the weight of the globe when filled with gas be 15 grains in excess of the counterpoise, which equals the weight of the globe when exhausted, and also that the weight of air indicated to be contained in the globe at 60° F. and 30-

inch barometer be 31 grains. Further, that the observed temperature of the gas be 56° F. and the barometric pressure 30.3 inches.

RULE.—Multiply the ascertained weight of the gas by 1000 and divide by the number (Table D, Appendix) for temperature and pressure. Finally, divide the quotient first obtained by the weight of air which the globe contains at 60° and 30 inches.

EXAMPLE.—Weight of gas..... 15 grains.
Multiply by..... 1000

Number for 56° and 30.3 inches... 1020) 15000 (14.7058

Weight, corrected to standard temperature and pressure, 14.7058 grains.

Which corrected weight, divided by the weight of air, 31 grains, indicates the relative weight, or specific gravity, of moist gas to moist air to be as .4743 to 1.0 or 474.3 to 1000.

269. In following the method of determining specific gravity of gas by weighing a globe referred to in paragraph 261, the volume of gas operated upon must be known. This can be easily ascertained from the following data, if the weight of air contained at 60° and 30 inches in the globe employed has been once correctly determined:

270. DATA.—*At Standard temperature and pressure.*

(a) One cubic foot of moist air weighs 532.4 grains, while one cubic foot of dry air weighs 535.9 grains.

(b) One cubic inch, therefore, of moist air weighs .3081012 grain, and of dry air .3101214 grain, and, as quite near enough, 100 cubic inches of moist air weigh 30.81 grains.

(c) One cubic foot of moist air or gas contains 5.8 grains of water vapour, or .33565 of a grain (say .336 of a grain) in 100 cubic inches. The weight of air, therefore, contained in 100 inches of such a mixture would be 30.81 — .336, or 30.474 grains.

271. The weight of air contained in the globe is, as already said, determined at 60° and 30 inches barometer, with the air saturated with water vapour. Suppose the globe has been found to contain 30.964 grains, and is so marked :

RULE TO FIND CAPACITY.—Divide the marked weight of air contained in the globe by 30.81.

EXAMPLE.— $\frac{30.964}{30.81} = \text{volume, or } 100.5 \text{ cubic inches.}$

272.—Suppose, as before, the weight of gas contained were 15 grains :

RULE TO FIND THE WEIGHT OF 100 CUBIC INCHES.—Multiply the ascertained weight by 100, and divide by the capacity of the globe.

EXAMPLE.— $\frac{15 \times 100}{100.5} = \frac{1500}{100.5} = 14.9254 \text{ grains,}$

which is the weight of 100 cubic inches of moist gas at the observed temperature and pressure.

273. *To Find the Specific Gravity of Dry Gas.*—Multiply the weight as above corrected by 1000, and divide by the number due to temperature and pressure (Table D, Appendix).

Subtract .336 of a grain from the quotient, and divide the remainder by 30.474 (270 c).

EXAMPLE.—Weight corrected for bulk.... 14.9254

Multiplied by 1000..... = 14925.4

Divided by number for 56° and 30.3 inches,
1020 = 14.6323
Subtract 336

Divided by..... 30.474) 14.2693

Specific gravity of dry gas..... = .469

274. *To Correct the Bulk and Find the Weight of Gas.*—*Bulk:* Multiply the quantity of gas by the tabular number

due to temperature and pressure, strike off the three right-hand figures, and the remainder is the true bulk. If the gas be subjected to pressure in excess of that of the atmosphere at the time of measuring, add one inch to the barometer's height for every thirteen inches of water pressure.—*Weight:* Multiply the quantity in cubic feet by the specific gravity, and strike off the three right-hand figures, then multiply the remainder by .07605 or .076.

275. The following is the method devised by Mr. Greville Williams, F.R.S., for the determination of the specific gravity of gas, a description of which appeared in the Transactions of the Gas Institute for 1882:

"The specific gravity of a gas may be defined as the comparative weights of equal volumes of air and the gas under the same conditions as to temperature and pressure. Whether the gas should be dried or not before its density be taken is a matter of no importance as regards the present paper. I, however, invariably weigh the gas and air in an absolutely dry state. It is quite unnecessary for me to state the processes devised by Regnault, Bunsen, and others, as I have already done so very fully in Watt's 'Dictionary of Chemistry' and in my 'Handbook of Chemical Manipulation.' . . . The sole object of this paper is to show that, by a simple modification of well-known processes, and without the use of an air-pump, an accuracy may be obtained which leaves nothing to be desired for technical purposes; and the formula given for the calculation, which is of the utmost possible simplicity, does not introduce an error of any importance.

276. "If, however, perfect accuracy be desired, the corrections mentioned further on can be easily made. As with the method described by Banister, only a globe with two stop-cocks is used. Instead, however, of weighing the balloon, as Banister directs, against weights, I weigh against another balloon of as near as possible the same size, but a little lighter—a device very generally adopted in the determination of specific gravities of gases and vapours.

"The determination of the specific gravity of a gas is by no means a difficult operation; but, nevertheless, to

obtain accurate results, attention must be paid to the minutest precautions, the neglect of any one being fatal to success. In the first place, the balance should be of the highest class; both planes and edges must be of agate or rock crystal, and it should distinctly indicate one decimilligramme with the globe and its counterpoise hanging from the beam. If this be the case, the capacity of the globe need not be greater than 400 cubic centimetres.

"The usual methods employed involve exhaustion of the balloon by the air-pump, either at each experiment or, as with Letheby's, a preliminary exhaustion, which serves once for all. By the method here described, not only is no exhaustion required, but all corrections are avoided by the simple device of selecting the day when the barometer is steady, and working in a room where the temperature can be made the same when the globe is weighed with air as when it is weighed with gas. Both these conditions, I find, can be readily obtained in practice.

277. "The room in which I worked formed the centre one of a series of three, and had no doors; notwithstanding this, by means of a gas stove, I found it easy to regulate the temperature to 0.2 of a degree Centigrade.* If the room be too cold, the heat may be raised; if it be too hot, cooler air may be introduced by the ordinary means employed for ventilation. By working in this way, it will be seen that the air and the gas may be weighed under the same conditions of temperature and pressure. It is proper, however, to remark that the air must be rendered absolutely free from carbonic anhydride and moisture. For this purpose, it was drawn slowly through one bottle of potassium hydrate solution, two of sulphuric acid, six U-tubes of very active soda-lime, and four U-tubes of calcic chloride, before entering the globe. One U-tube of calcic chloride was placed, as a guard, after the globe.

"The drawing through of the air is effected by means of an aspirator, and the current is kept up until every trace of any gas previously experimented on is removed; this may be known by the balloon remaining constant in weight. When this is arrived at, and the temperature at which it is desired to make the experiment attained (and which should be as near as possible the average of the room), the tube attached to the aspirator is to be

*The thermostat referred to in Chapter II. enables the temperature of the room to be regulated with ease. J. A.

slipped off, and the tap of the globe on that side closed, and then the other tap. The balloon having been carefully wiped with a clean chamois leather, or a soft, silk handkerchief kept for that purpose, is to be hung on the balance by a stirrup of platinum wire. The counterpoise is also to be hung on the balance by the glass hook. The counterpoise being somewhat lighter than the balloon, a very few grammes will be required to bring them into equilibrium.

"Having adjusted the last deci-milligramme, by means of the rider apparatus, the balloon is to be left for five minutes, and the weight taken again; the last weight is to be called 'weight of balloon and air.' The balloon is then to be attached to a tube evolving the gas, which is to be passed slowly through six U-tubes of soda-lime, to remove the last traces of carbonic acid, and four of calcic chloride for one hour, a guard tube, as before, being employed at the exit. The tap next the gas supply is to be turned off first, the other immediately after; the balloon is then to be weighed with the same precautions as were taken with the air. It is as well, in a first experiment, to send the gas a second time through the globe for another half-hour; when, if it be found that the globe has not diminished in weight, it is, of course, certain that all the air has been expelled. The last weight is to be entered in the laboratory book as 'weight of balloon and gas.'

"From this time a specific gravity may be determined every hour without reweighing the balloon and air as long as the barometer and thermometer remain the same. The weights of the balloon and air at various barometric pressures and temperatures should be tabulated, as when that pressure and temperature occur again, the previous determination of weight of air will render another one unnecessary.

278. "It is obvious that the temperature of the room in winter will be different to that in summer, but this will have no effect upon the result, as all that is necessary is that the temperature should be the same when both gas and air are weighed.

"Care must be taken that the calcic chloride and soda-lime are renewed at proper intervals.

279. "In order to subject the process to the severest possible test, I made some determinations of the specific gravity of hydrogen in the globe, having a capacity of 443 cubic

centimetres. The specific gravity of hydrogen being only 0.0693, it will be seen that an error of only 0.01 is very conspicuous. In four experiments the following values were obtained:

No.	P Gms.	V c. c.	T C	n_t	D	Theory	Difference
I.	0.5038	443	16°	0.001221	0.0685	0.06930	-0.0008
II.	0.5045	443	14°	0.001230	0.07412	0.06930	+0.00482
III.	0.5020	443	16°	0.001221	0.07192	0.06930	+0.00262
IV.	0.5040	443	16°	0.001221	0.0682	0.06930	-0.0011

Mean.

Theory.

Difference.

0.0707

0.0693

+ 0.0014

"If all the corrections are made, the mean density becomes a little higher, but even then the error is only 0.0126, which is well within the limits laid down at starting. Bunsen's standard experiments with his apparatus gave 0.079; difference, 0.010.

280. "In the above table P is the difference between the weight of the balloon and air, and the balloon and gas, in grammes. V is the capacity of the balloon in cubic centimetres; T the temperature Centigrade; n_t the weight of one cubic centimetre of air at T ; D the experimental specific gravity. As care has been taken that the barometer shall not vary during the experiment, it does not enter into the formula, which for gases lighter than air is:

$$D = \frac{Vn_t - P}{Vn_t}$$

"The value of n_t may, when extreme exactitude is not required, be taken direct from the following table; otherwise n_t should be corrected for the elastic force of the atmosphere at the time of the experiment, as the table is calculated for a barometric pressure of 760 millimetres, or 29.922 inches.

281. TABLE FOR THE CALCULATION OF n_t .

Temperature		n_t Grammes	Temperature		n_t Grammes
C.	F.		C.	F.	
Deg.	Deg.		Deg.	Deg.	
1	33.8	0.001288	16	60.8	0.001221
2	35.6	0.001284	17	62.6	0.001217
3	37.4	0.001279	18	64.4	0.001213
4	39.2	0.001275	19	66.2	0.001209
5	41.0	0.001270	20	68.0	0.001205
6	42.8	0.001266	21	69.8	0.001201
7	44.6	0.001261	22	71.6	0.001197
8	46.4	0.001257	23	73.4	0.001193
9	48.2	0.001252	24	75.2	0.001189
10	50.0	0.001248	25	77.0	0.001185
11	51.8	0.001243	26	78.8	0.001181
12	53.6	0.001239	27	80.6	0.001177
13	55.4	0.001234	28	82.4	0.001173
14	57.2	0.001230	29	84.2	0.001169
15	59.0	0.001225	30	86.0	0.001165

"It is as well to repeat that the flow of a light gas should be continued until the balloon ceases to lose weight; and if the gas be heavier than air, until it ceases to gain weight.

282. "The following numbers were obtained in the determination of the density of carbonic anhydride:

No.	P. Gms.	V. c. c.	T. C.	n_t	D.	Theory	Difference
I.	0.2833	443	17°	0.001217	1.5254	1.5224	+0.0030
II.	0.2855	443	17°	0.001217	1.5295	1.5224	+0.0071
Mean.				Theory.		Difference.	
1.5274				1.5224		-0.0050	

"The gas being heavier than air, the formula becomes:

$$D = \frac{V n_t + P}{V n_t}$$

"In conclusion, it may be said that, if the method above given be carefully carried out, the specific gravity of coal or any other gas of which a cubic foot or two can be spared may be readily and accurately determined without the use of an air-pump."

283. Another method of ascertaining the specific gravity of gas is that devised by F. Lux. The apparatus is shown

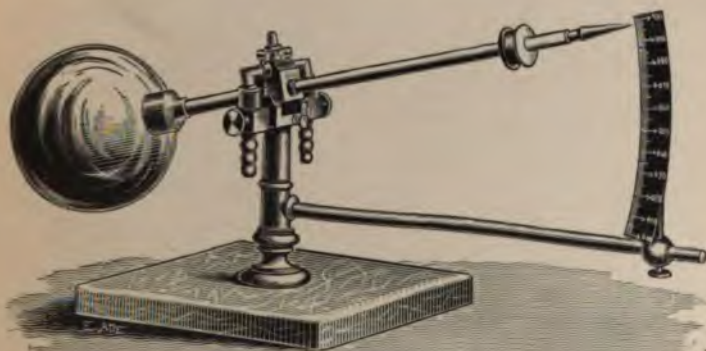


FIG. 40a.—LUX SPECIFIC GRAVITY BALANCE.

in Fig. 40a, and is, as will be seen, made on the principle of the common lever balance. The gas is introduced to the globe of the balance, which is suspended on pivots, the gas-ways being sealed by mercury cups, and passes away to a convenient service. The balance being adjusted, the specific gravity (uncorrected for temperature, atmospheric pressure, and aqueous vapour) is read direct on the scale. This is calibrated by weighing air in the globe at 15° Centigrade

and 760 millimetres' pressure and marking the indicated point as 1 and then weighing hydrogen under the same conditions and marking the scale 0.07. The scale is then subdivided and after the proper adjustment of the balance, the specific gravity of Mond gas is indicated.

The corrections are made as follows:

Barometric Pressure.—For every millimetre at which the barometer stands above or below 760 millimetres, 0.001 is added or deducted from the specific weight indicated on scale.

Temperature.—For every degree Centigrade at which the thermometer stands above or below 15°, 0.002 must be deducted or added.

The instrument requires very careful adjustment, and the writer's experience with this balance has not led him to think with the inventor that it is one by which "specific gravity of gas may be ascertained in the same automatic way in which it is possible to ascertain temperature and pressure by means of the thermometer and barometer." In the hands of a careful experimentalist it affords another means beyond those mentioned above of ascertaining specific gravity of coal, furnace, generation or other gas. Whether it is better or worse must be a matter of opinion.

A Note on Mond Gas.

285. It is stated of the Mond gas plant that in it "is found a perfect system of producing cheap power-gas, which, when combined with the use of gas-engines, forms the cheapest, most scientific, and the most economical method of dealing with fuel." This statement was made by Mr. Herbert A. Humphrey (Proceedings Inst. Mech. E., January, 1901), whose figures quoted below will no doubt enable a compari-

son to be made between the above claims and those of other methods of gas fuel production.

286. Mond gas is particularly interesting because Parliamentary powers have recently been obtained for the supply of this fuel for industrial purposes, and steps are already being taken (as witness the abstract of the South Staffordshire Mond Gas Company's Act, quoted below) to put these Parliamentary powers into action. The arguments which have been adduced for and against the Mond Gas bill will be fresh in the minds of all. The bill is now a "*fait accompli*," and it appears to the writer that gas manufacturers will best serve the interests of their undertakings by profiting by the experience which will be obtained from the practical working of the new power gas companies.

287. Some of the clauses in the South Staffordshire Mond Gas (power and heating) Company's Act provide as follows:

Gas shall not be supplied for purposes of illumination nor to private dwelling houses. If any consumer is found to be using the gas for illumination the supply shall be cut off.

Gas shall not be supplied unless the user undertakes to contract for not less than one million cubic feet per annum.

If required, applicants are to enter into a written contract to take not less than one million cubic feet per quarter, and to continue taking it for not less than two years.

For the purposes of determining the amount as between buyer and seller a "proportional" meter, *i. e.*, a meter which measures and records a fraction of the total quantity passed through the meter, shall be deemed sufficient.

Any breaches by the Company of the above provisions shall be punishable by penalties and fines recoverable by the owners of the gas undertaking of the district.

The charge for gas is to be as agreed upon, but is not to exceed 3d. per 1000 cu. ft. for over four million cu. ft. per quarter, and 4d. per 1000 cu. ft. for less amounts.

This price is liable to increase if the price of "good quality slack" exceeds 6s. per ton delivered at the Company's works, such authorised increase in the price of the



gas to be one-eighth of a penny per 1000 cubic feet for every shilling per ton, or as otherwise determined by the Board of Trade.

The gas shall not contain more than 14 per cent. of carbon monoxide.

The gas shall have a perceptible smell.

The gas shall be of a minimum heating value of 125 B. T. U. per cubic foot.

Apparatus for ascertaining the thermal power and quantity of CO is to be kept at every generating station.

Gas Examiners may be appointed by local authorities or justices.

Failure in above conditions of supply is punishable by fines.

288. The following is a short description of the method of making Mond gas with the recovery of ammonia :

The fuel used is common bituminous slack, which is elevated into hoppers above the producers. It is fed into the bell of the producer in charges of 8 to 10 cwts., and after it has first been heated the products of distillation are passed downward into a hot zone of fuel before joining the bulk of gas leaving the producer. By this means the tar is destroyed and converted into a fixed gas; the heated slack then passes downward into the body of the producer, where it is acted upon by an air blast saturated with steam at 185° Fahr., and superheated before coming in contact with the fuel. A large amount of steam is introduced, and in this respect the practice is different to that obtaining in other producers, the quantity of steam being about 2½ tons for every ton of fuel gasified. By this means the temperature is kept comparatively low, so that no coke is formed, and the ammonia is not destroyed; but at the same time good ashes are obtained. Of the steam introduced with the blast into the producer half a ton is decomposed for every ton of fuel used, yielding about 29 per cent. of hydrogen. The hot producer gas and undecomposed steam now pass through a regenerator, through which the blast is passing (before entering the producer) in a reverse direction; in this way a good deal of the heat from the producer gas is given up to the blast, thus yielding an economy. The gas and the unde-

composed steam are then passed through a washer and reduced to about 194° Fahr. The producer gas then passes to the first tower, in which it meets a downward flow of acid liquor circulated by pumps, containing sulphate of ammonia with about 4 per cent. of free sulphuric acid. This combines with the ammonia, forming more sulphate liquor, and in order to render the process continuous, some of this latter is constantly withdrawn, being replaced by free acid. The gas, now freed from ammonia, passes into a water-cooled tower, where it meets a downward flow of cold water. The steam is condensed by this and the gas is finally cooled, and in this manner the cold water is converted into hot water, which is passed into a third tower, where it meets the air-blast, thus increasing the temperature of this latter and itself being reduced proportionally. In this manner all the heat of the gas from the producer is utilised—nearly a ton of steam being added to the producer-blast for every ton of fuel gasified. Mr. Herbert A. Humphrey (engineer to Brunner, Mond & Co.) says: "This cyclical exchange of heat is always going on, and forms one of the distinctive features of the economy of the process. The hot water from the gas-cooling tower is circulated through the air-heating tower, and, being thereby cooled, is again pumped up to the top of the gas-cooling tower. Both towers are filled with tiles to give large surfaces of contact, and the circulating water acts as the heat-carrying agent between the hot gas and the cold air."

The process is not interrupted by feeding fresh fuel into the producer, and the withdrawing of ashes, and the large volume of steam used keeps the gas at a constant quality.

289. It will be seen that the process differs from other producers, in that all the carbon (less ash) is converted into gas, and that a large proportion of the cost of the fuel (under favourable circumstances, 75 per cent.) is recovered as sulphate of ammonia.

The following figures are given by Mr. Humphrey. (See proceedings Inst. Mech. E., January, 1901.):

Average analysis of fuel (by weight):

	Slack as received. Per cent.	Dry slack. Per cent.
Moisture at 100° C. (212° Fahr.) ...	8.60	—
Volatile matter (excluding carbon) ..	18.29	20.01
Total carbon	62.69	68.59
Ash	10.42	11.40
	100.00	100.00

Analysis of ashes leaving the producer:

	Per Cent.
Ash on dried sample, by weight	87.0
Carbon	13.0

	Per Cent.
Total carbon lost in ashes, etc., calculated on fuel used	5.31
Carbon available for conversion into gas...	57.38

Calorific value of fuel (dry sample):

By bomb calorimeter, kilo-calories	6786
Kilo-calories per ton of dry fuel	6,894,576

Typical volumetric analysis of Mond gas (dry):

	Vol. per cent.
Carbon monoxide (CO) (carbonic oxide) ..	11.0
Hydrogen (H)	29.0
Marsh gas (CH ₄)	2.0
Carbon dioxide (CO ₂) (carbonic acid)	16.0
Nitrogen	42.0
	100.0

Weight of 1 c.m. (35.32 cu. ft.) dry gas at 0° C.	= 1.020 gms., 2.24 lbs.
Weight of 1000 cu. ft. of dry gas at 0° C.	= 63.66 lbs.
Specific gravity of Mond gas (air = 1)	= 0.7882

Each kilogramme (2.2 lbs.) of (moist) fuel gasified yields:

3.690 c.m. (130.33 cu. ft.) of dry gas at 0°C.
3.959 c.m. (139.79 cu. ft.) gas saturated at 15°C. (59° Fahr.)

One ton of (moist) fuel gasified yields:

132.414 cu. ft. (3,749.0 c.m.) dry gas as above.
142.069 cu. ft. (4,022.3 c.m.) gas saturated as above.

Calorific value of Mond gas (products cooled to 18°C. [64° Fahr.]):

	Dry. as above.	Saturated
1 cubic metre in kilo-centigrade units..	1414.3	1317.8
1 " foot in lb.-degree-centigrade units	88.26	82.25
1 cubic foot in B. T. U.'s	158.8	148.0

Calorific value of total gas made in percentage on calorific value of total fuel gasified = 84.1%.

Combustion of Mond gas and air:

One volume of gas requires for perfect combustion 1.15 vols air.
Volume of mixture before combustion.. 2.15 vols. at 0°C.
Volume of products (cooled to 0°C.).. 1.95 vols.
Contraction due to combustion..... 9.3 per cent.

One c.m. (35.32 cu. ft.) gas, weighing 1.02 kilos (2.2 lbs.), requires for combustion 1.15 c.m. (40.62 cu. ft.) air, weighing 1.487 kilos (3.3 lbs.), and yields 1.94 c.m. (68.9 cu. ft.) of products weighing 2.507 kilos (5.5 lbs.).

The gas generated by gasifying one kilo (2.2 lbs.) of moist slack requires for combustion 4.243 c.m. (149.86 cu. ft.) of air, weighing 5.846 kilos (12.1 lbs.), and yields 7.195 c.m. (254.13 cu. ft.) of products at 0°C. weighing 9.243 kilos (20.3 lbs.).

If Mond gas is burnt with the theoretical quantity of air, the products, tested on the dry sample, should show 17.9% CO₂ by volume.

Specific heat of Mond gas at constant pressure..	0.3201
“ “ “ “ “ volume ..	0.2321
Ratio =	1.379
Specific heat of products of combustion at constant pressure	0.2622
Specific heat of products of combustion at constant volume	0.1922
Ratio =	1.364
Theoretical temperature of combustion of Mond gas in air, both being at 15°C. (59° Fahr.) before combustion	1611°C. (2932° F.)
Temperature actually obtained without regeneration	1100°C. (2012° F.)

[NOTE.—Pars. 290-299 are left blank to facilitate additions in a future edition.]

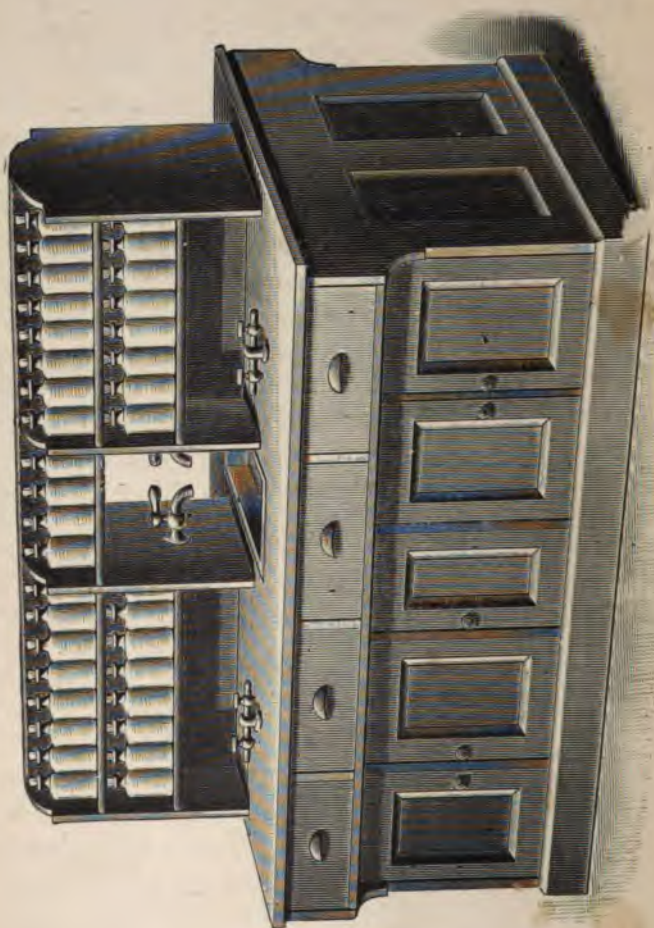
CHAPTER V.

THE REFEREES' TEST FOR PURITY.

300. Most of the gas companies in the United Kingdom are under no more stringent obligations in respect to the purity of gas they supply than that which is specified in the Schedule A, Part II., of the Gas Works Clauses Act of 1871 (par. 15). But when any gas company is under obligations similar to those imposed upon the gas companies of London, then it becomes the duty of the analyst to ascertain not only (1) the freedom of the gas from sulphuretted hydrogen, but also (2) the quantity of ammonia, and (3) the quantity of sulphur, "other than sulphuretted hydrogen," which 100 cubic feet of the gas contains.

Time and Mode of Testing for Purity in London.

301. The testings for purity shall extend over not less than fifteen hours of each day, and shall be made upon ten cubic feet of gas. The gas shall be tested successively for sulphuretted hydrogen, ammonia, and sulphur compounds other than sulphuretted hydrogen. These testings must be started between 9 A.M. and 5.30 P.M., and must be concluded before 9 A.M. on the following morning. They are concluded by the action of the automatic lever tap, attached to the meter, which stops the passage of the gas when ten cubic feet have passed. A clock, connected with the lever tap, is stopped at the same moment, leaving a record of the time; and the tap of an Aerorthometer is turned, leaving a record of the



CHEMICAL BENCH.

final conditions under which the gas was measured by the meter.

302. The liquids in the sulphur and ammonia tests and the slips of paper in the tests for sulphuretted hydrogen then contain the sulphur and ammonia which were present in the gas supplied to the testing place during the day which ended at 9 A.M. The chemical examination of these liquids may be made on the following day—that is, after 9 A.M. The gas-testing day begins at 9 A.M. of one civil day and ends at 9 A.M. of the next. The date is that of the civil day on which it begins. (The City of London Gas Act, 1868, Section 2.)

Sulphuretted Hydrogen.

303. The gas shall be passed as it leaves the service pipe through an apparatus in which are suspended slips of bibulous paper impregnated with basic acetate of lead. The test-paper from which these slips are cut is to be prepared from time to time by moistening sheets of bibulous paper with a solution of one part of sugar of lead in eight or nine parts of water, and holding each sheet while still damp over the surface of a strong solution of ammonia for a few moments. As the paper dries all free ammonia escapes. If distinct discoloration of the surface of the test-paper is found to have taken place, this is to be held conclusive as to the presence of sulphuretted hydrogen in the gas. Fresh test-slips are to be placed in the apparatus every day. In the event of any impurity being discovered, one of the test-slips shall be placed in a stoppered bottle and kept in the dark at the testing place; the remaining slips shall be forwarded with the daily report. The gas must be wholly free from sulphuretted hydrogen.

Ammonia.

304. The gas which has been tested for sulphuretted hydrogen shall pass next through an apparatus consisting of a glass cylinder filled with glass beads cut from lengths of small, hard glass tubing which have been moistened with a measured quantity of standard sulphuric acid. A set of burettes, properly graduated, is provided. The maximum amount of ammonia allowed is four grains per one hundred cubic feet of gas, and the testings shall be made so as to show the exact amount of ammonia in the gas.

Sulphur Compounds Other than Sulphuretted Hydrogen.

305. The gas which has been tested for sulphuretted hydrogen and ammonia shall pass next through a meter by means of which the rate of flow can be adjusted to half a cubic foot per hour, and which is provided with a self-acting movement for shutting off the gas when ten cubic feet have passed, for stopping a clock so as to indicate the time at which the testings terminated, and for turning the tap of the recording Aerorthometer. The gas examiner shall enter in his book the time thus indicated, as also the time at which the testings began.

306. The clock when required is a good pendulum clock with a wire passing transversely through the case behind the pendulum. Outside the case a lever arm is clamped to the wire, so that when liberated the arm will drop, and turn the wire. Inside the case an arm is clamped to the wire, and at the end of the arm a flexible wire is fastened; when the lever drops, this flexible wire is brought into gentle frictional contact with the pendulum, so as to stop it without shock. The clock should be wound from the front, and both hands should be mounted so that they can be set indepen-

dently from the front. It is desirable that the clock should be able to go for a week with one winding. From the meter the gas passes to the "sulphur test," where it is burned in air impregnated with ammonia, the water-vapour which is formed being condensed and collected, and with it the sulphur and other condensable products which arise from

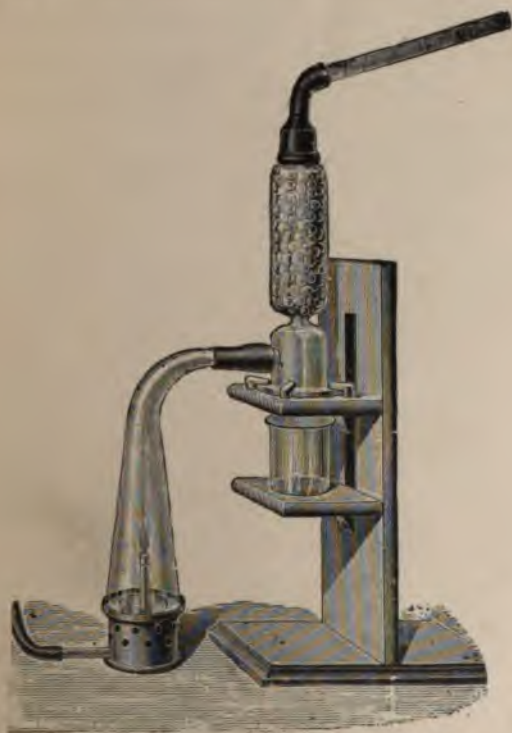


FIG. 41.—REFEREES' SULPHUR TEST.

combustion. The maximum amount of sulphur allowed in the metropolis in summer is seventeen grains per one hundred cubic feet, and in winter 22 grains.

307. The apparatus is represented by Fig. 41, and is of the following description: The gas is burned in a small Bunsen

burner with a steatite top, which is mounted on a short cylindrical stand perforated with holes for the admission of air, and having on its upper surface a deep circular channel to receive the wide end of a glass trumpet-tube. There are both in the side and in the top of this stand fourteen holes of five millimetres in diameter or an equivalent air way. On the top of the stand, between the narrow stem of the burner and the surrounding trumpet-tube, are placed pieces of commercial sesqui-carbonate of ammonia, weighing in all about two ounces. Much of the sesqui-carbonate sold contains bicarbonate of ammonia, and the excess of CO_2 materially interferes with the condensation of the sulphur acids. However, two or three pieces of the carbonate, each about the size of a marble, placed on the top of the balls in the condenser, will, according to Mr. Heisch's experience, induce proper condensation. The products both of the combustion of the gas and of the gradual volatilisation of the ammonia salt go upward through the trumpet-tube into a vertical glass cylinder with a tubulure near the bottom, and drawn in at a point above this to about half its diameter. From the contracted part to the top the cylinder is packed with balls of glass about fifteen millimetres in diameter, to break up the current and promote condensation. From the top of the cylinder there proceeds a long glass eduction tube or chimney, slightly bent over at the upper end, serving to effect some further condensation, as well as to regulate the draught and afford an exit for the uncondensable gases. In the bottom of the cylinder is fixed a small glass tube, through which the liquid formed during the testing drops into a flask placed beneath.

308. *The following cautions are to be observed in selecting and setting up the apparatus:*

See that the inlet pipe fits gas-tight into the burner, and that the holes in the circular stand are clear. If the burner

gives a luminous flame, remove the top piece and, having hammered down gently the nozzle of soft metal, perforate it afresh, making as small a hole as will give passage to two-thirds of a cubic foot of gas per hour at a convenient pressure.

See that the tubulure of the condenser has an internal diameter of not less than eighteen millimetres, and that its outside is smooth and of the same size as the small end of the trumpet-tube, also that the internal diameter of the contracted part is not less than thirty millimetres.

See that the short piece of india-rubber pipe fits tightly both to the trumpet-tube and to the tubulure of the condenser.

The small tube at the bottom of the condenser should have its lower end contracted, so that when in use it may be closed by a drop of water.

The india-rubber pipe at the lower end of the chimney tube should fit over, and not simply rest upon, the mouth of the condenser. A central hole may with advantage be made in the shelf of the table or stand. If the beaker is kept on the table below, the liquid will still be preserved if by any accident the flask is not in its place.

309. The arresting of the ammonia by acid, and the burning of the gas under the conditions indicated, are preliminary processes. The after processes consist in the finding (1) the quantity of acid which has entered into combination with the ammonia from the gas, and (2) the weight of barium sulphate precipitated from the condensed products of combustion on the addition of hydrochloric acid and barium chloride.

Preparation of Solutions.

310. For estimating the quantity of ammonia in gas two solutions are required, one containing 1 grain of ammonia (NH_3) in 100 measures of the solution, the other containing a little more than 2.88 grains of sulphuric acid (SO_4H_2) in 25 measures of the solution—that is, such a quantity of acid as will combine with and completely neutralise *one*

grain of ammonia, and for the preparation and use of these the following glass vessels are required: A mixing jar (Fig. 42), graduated into 100 parts, which when charged with any fluid to the 100th line, *while standing on a level base*, measures exactly one-tenth of a gallon of such fluid; pipettes (Fig. 43), which when charged with liquid up to

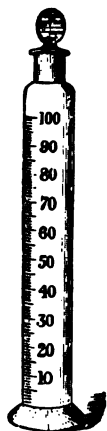


FIG. 42.
MIXING JAR.



FIG. 43.
PIPETTE.

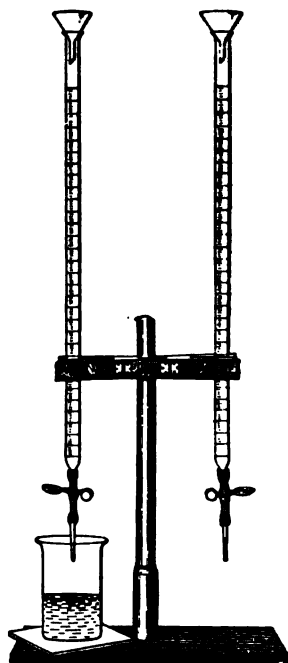


FIG. 44.
STAND WITH BURETTES.

the mark on the stem deliver an exact number of septems; two burettes (Fig. 44) on a wooden stand, one for use with acid solution, and the other for use with alkaline solution. Each burette is graduated into 100 parts (septems), and each part is subdivided into fifths. A septem is equal to the one ten-thousandth part of a gallon, or to seven

grains' weight of pure water at 62° Fahr. These burettes are furnished with Mohr's pinch-cocks, Erdmann's floats, and with funnels.

311. *Sulphuric Acid*.—The gravity of pure strong acid is 1.846, its composition SO_4H_2 , and its combining weight 98. The weight of the two molecules of ammonia, required to satisfy 98 of strong acid, is 34, so that 2.8824 grains of the acid are required to combine with 1 grain of ammonia. One septem of such acid weighs 12.922 grains; consequently, about 9.2 septems of it are required in the decigallon of the solution, which should neutralise four times its own volume of the standard ammonia solution; but as strong acid is likely to be somewhat below 1.846 gravity,



FIG. 45.—MANIPULATING PIPETTE.

it is better to have a slightly excessive quantity; therefore, charge the decigallon mixer while it stands on a level base with pure distilled water until the centre of the meniscus, or hollow of the water surface, coincides with the *top* line of the mixer, then add as nearly as possible 9.4 septems of pure concentrated sulphuric acid, which may be accomplished either by the use of a properly divided burette or by the assistance of a graduated pipette. If the latter, hold the pipette between the fingers and thumb, dip the pipette into the strong acid until it is charged up to the requisite line on the stem. Press the forefinger, previously moistened, firmly on the opening at the upper end (Fig. 45), and pass the pipette and contents over to the open mouth of the mixer. Lift the forefinger, and the contents of the pipette

will fall into the mixer. Insert the stopper of the mixer tightly, and well shake the vessel. Water containing impurities is sometimes sold as "distilled." Acidulate a portion with a few drops of diluted hydrochloric acid, and then add chloride of barium solution. Add to another portion diluted nitric acid, and then a little nitrate of silver solution. Both portions should remain clear.

312. If it be desired to prepare a larger quantity of the test acid at one time, "measure a gallon of distilled water into a clean earthenware jar or other suitable vessel. Add to this 94 septems of pure concentrated sulphuric acid, and mix thoroughly." A *decigallon* of water and 9.4 septems of strong acid will together equal the volume of 1006.9, instead of 1009.4, septems, while a *gallon* of water with 94 septems of concentrated acid will, of course, be equal to 10,069 septems.

313. To determine the strength of the test acid, remove 50 septems of it from the mixer or vessel in the following manner: Take a clean and dry 50-septem pipette, dip its *point* into the solution, apply the lips to the upper end, and suck until the liquid rises to a little above the mark on the stem. Caution must be used in filling the pipette with solutions, in order to avoid their entry into the mouth. The point of the pipette must be kept well immersed while sucking. Strong ammonia, strong acids, and all fluids which give off fumes of poisonous or irritating character, must not be so sucked. Cease sucking, and immediately press the finger on the top in the way directed in par. 311. The pipette can be properly charged only in this way when used as an exact measure, as its exterior must then be kept dry. Hold the pipette before the eyes, and by partly raising the forefinger allow any excess of acid to drop from the point into the mixer, until the centre of the curved surface of the liquid coincides with the mark on the stem; imme-

diately transfer the 50 septems of liquid to a clean beaker or flask, and to insure the delivery of the last drop, gently blow through the pipette while its point is touching the side of the glass vessel.

314. Treat the liquid with barium chloride, and determine the quantity of sulphate produced as described in par. 324 *et seq.* "The weight of barium sulphate which 50 septems of test acid should yield is 13.8 grains. The weight obtained with dilute acid prepared as above will be somewhat greater, unless the sulphuric acid used had a specific gravity below 1.846." To determine the quantity of water which must be added to the solution, divide the number of septems of test acid contained in the mixer or vessel by 13.8, and multiply the quotient by the difference between 13.8 grains and the number of grains of sulphate obtained. Thus, with a *deci-gallon* of water and 9.4 septems of strong acid the original volume will be 1006.9 septems, and after 50 septems have been removed there will remain 956.9 septems, which, divided by 13.8, gives a quotient of 69.34. If the excess of sulphate be 0.15 grain, then 69.34×0.15 gives 10.4, the number of septems of water needful to be added. If a gallon of water be used with 94 septems of strong acid, the original volume will be 10,069 septems, and after the abstraction of 50 septems there will remain 10,019 septems, which, divided by 13.8, will give a quotient of 726, which, multiplied by 0.15, will give 108.9 septems as the quantity of water to be added. "If these operations have been accurately performed, a second precipitation and weighing of the barium sulphate obtainable from 50 septems of the test acid will give nearly the correct number of 13.8 grains. If the weight exceed 13.9 or fall below 13.7, more water or sulphuric acid must be added until the weight falls within those limits."

315. If, on a second precipitation and weighing, the test

acid is found still to be too strong, the additional quantity of water to be added may be found by the above rule, but regard must be given to the quantity of solution, thus: The 956.9 septems mentioned will have been increased to 967.3, about, by the addition of 10.4 septems of water; and after the abstraction of 50 septems for a second test there will remain 917.3 septems only to be divided by 13.8, in order to obtain a quotient to be multiplied by the excess weight of sulphate obtained. "The test acid thus prepared should be transferred at once to stoppered bottles which have been well drained and duly labelled."

316. *Ammonia*.—Strong solution of ammonia has usually a gravity of about .88, and contains about two grains of absolute ammonia (NH_3) per septem. Hence, 5 septems to the decigallon should give a solution of nearly the right strength. If it be desired to make a larger quantity, measure a gallon of distilled water into a clean glass vessel, "and mix it with 50 septems of strong solution of ammonia (specific gravity 0.88). Try whether 100 septems of the test alkali thus prepared will neutralise 25 of the test-acid; if the acid is just neutralised by the last few drops, the test alkali is of the required strength." To perform this experiment, the burettes (Fig. 44) must be used. Fix the burettes perfectly upright at a convenient elevation on the stand. Pour a few septems of the ammonia solution into one of the burettes. Place a glass beaker below the burette, open the pinchcock, and let the solution flow out. Charge the burette fully with a fresh portion of the solution, and remove the funnel. Charge the other burette in the same way with test-acid. Bring the engraved line of each float on a level with the top line of the burette by opening the pinchcock and letting any excess of solution drop into the flask or beaker.

NOTE.—*The burettes must be kept dry outside; if any*

solution flow over when charging them, they must be carefully wiped.

317. Place a perfectly clean glass beaker or a small flask below the burette and let fall into the vessel exactly 25 septems of acid solution, which color with two or three drops of tincture of logwood. Into the same vessel let fall from the second burette sufficient of the ammonia solution to change the colour of the liquid from yellow to pink. The last additions must be made in single drops, and the mixture shaken between each addition, or stirred with a glass rod. If more or less than 100 septems of the ammonia solution be required to neutralise 25 septems of the test acid, "small additional quantities of water or of strong ammonia solution must be added [to the solution in the decigallon mixer or jar], and fresh trials made, until the proper strength has been attained. The bottles in which the solution is stored should be filled nearly full, well stopped, and labelled."

Testing and Analysis.

318. The testing shall be made in a room where no gas is burned other than that which is being tested for sulphur and ammonia. The illustration (Fig. 46) of the sulphuretted hydrogen, ammonia, and sulphur apparatus shows clearly how the apparatus is set up, while the instructions given below are abundantly clear by reference to this illustration. It must be understood that the ammonia saturator is charged and connected, and the sulphur apparatus charged and connected, before the gas is allowed to pass through the meter, both the tests being made simultaneously and with the same gas. Thus, one meter serves for both tests, the SH_2 and ammonia tests being placed at the inlet and the sulphur test on the outlet of the meter.

To Make the Test for Ammonia.

319. The mode of testing is as follows: Take 50 septems of the test acid (which is greatly in excess of any quantity of ammonia likely to be found in the gas), and pour it into the glass cylinder or saturator, so as to well wet the whole interior surface and also the glass beads. Connect one terminal tube of the cylinder with the gas supply and the other with the meter, and make the gas pass at the rate of not more than two-thirds of a cubic foot per hour. Any ammonia that is in the gas will be arrested by the sulphuric acid, and a portion of the acid (varying with the quantity of ammonia in the gas) will be neutralised thereby. At the end of each period of testing wash out the glass cylinder and its contents with distilled water, and collect the washings in a glass vessel. Transfer one-half of this liquid to a separate glass vessel, and add a quantity of a neutral solution of litmus or other indicator in ordinary use, just sufficient to color the liquid. Then pour into the burette 100 septems of the test alkali, and gradually drop this solution into the measured quantity of the washings, stirring constantly. As soon as the color changes (indicating that the whole of the sulphuric acid has been neutralised) read off the quantity of liquid remaining in the burette. To find the number of grains of ammonia in 100 cubic feet of the gas, multiply by 2 the number of septems of test alkali remaining in the burette, and move the decimal point one place to the left.

Example:

Liquid remaining in the burette $13.4 \times 2 = 26.8$.
decimal point moved one place to the left = 2.68
grains per 100 cubic feet in the gas.

319A. The explanation of above calculation is as follows:

(a) 10 cubic feet of gas are burned and one-half of the acid liquor = 25 septems (see par. 319) and washings are operated upon.

(b) The solutions are made of such strengths that 25 septems of the fresh acid solution will neutralise 100 septems of the ammonia solution (this latter containing 1 grain of real ammonia per 100 septems). See par. 310.

(c) If after the titration is made there are 13.4 septems (as in above example) of NH_3 solution left in the burette, it follows that 86.6 septems of the solution or 86.6 hundredths (= 0.866 of a grain) of absolute ammonia have been used to neutralise the excess of H_2SO_4 contained in the acid solution. and therefore 13.4 hundredths (= 0.134) of a grain of ammonia were contained in the acid washings titrated.

(d) Half of the acid taken has been used in the titration, therefore this 0.134 grain ammonia must be multiplied by 2 = 0.268 grains.

But only 10 cubic feet of gas had been passed; therefore to find the quantity of ammonia in 100 feet multiply by 10.

Therefore $0.268 \times 10 = 2.68$ grains of ammonia in 100 cubic feet of gas.

320. The remaining half of the liquid is to be set aside, in case it should be desirable to repeat the volumetric analysis. This portion of the liquid is to be used in either of the two following cases :

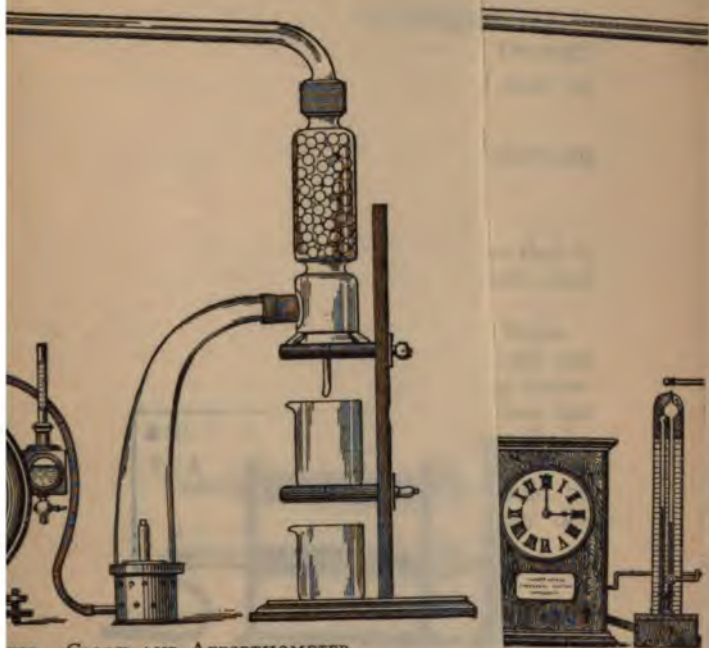
1. If the analysis of the first portion of the liquid show an excess of impurity, the gas examiner shall forthwith give the notice provided for in the acts of Parliament (the Gaslight and Coke Company's Act, 1876, sec. 40, and others) ; and if the company think fit to be represented by some officer, the second portion of the liquid shall be examined in his presence.

2. If the analysis of the first portion of the liquid should miscarry, or the gas examiner have any reason to distrust the result, he shall be at liberty to make an analysis of the second portion, provided that before doing so he give notice to the company, in order that they may, if they think fit, be represented by some officer.

Unless thus used, it is to be preserved, in a bottle properly labelled, for a week. It is sometimes found that a red or red-brown discoloration of the beads has taken place in the ammonia cylinder or saturator. This consists partly of a deposit of pyrrol-red, which is formed by the action of pyrrol (C_4H_4NH) on the sulphuric acid solution with which the glass beads are wetted. The action upon the sulphuric acid solution is so slight that it does not interfere with the accuracy of the test. Pyrrol is a product of the destructive distillation of coal, probably caused by the action of acetylene upon ammonia at a red heat. The red deposit can be removed by alcohol, afterward washing with water.

To Make the Test for Sulphur.

321. Set up but do not connect the apparatus as described in par. 307, and adjust the meter for its proper rate, not more than two-thirds of a foot per hour; turn the pointers of the meter by hand until they are a little before zero. A double-dry governor provided will keep the rate constant. Light the gas at the sulphur burner, and as the pointers come up to zero place the trumpet-tube in position on the stand, and connect its narrow end with the tubulure of condenser. At the same time the long chimney tube is attached to the top of the condenser. If necessary, secure the lever of the meter from falling and shutting off the gas. In the meter shown below, if the button with the stop pin on it is turned to the left, the stopping pointer will pass the 10-foot mark without shutting off. When it has passed this point turn the button to the right, and the gas will then be shut off when ten feet have been passed. The short pointer is only used for adjusting the rate by observation of one minute. The illustration (Fig. 46) shows the complete SH_2 sulphur and ammonia test as set up in a London testing station. Wind the



TER, CLOCK AND AERORTHOMETER.

[To face page 190.]

PHUR AND AMMO:



1

clock, set it to the right time, connect the stopping mechanism to the lever of the meter, and take a reading of the Aerorthometer, and connect same to lever of meter tap so that both will be stopped when ten feet have passed through meter; *keep record of Aerorthometer reading and time of commencing test.*

322. It will be found convenient to observe the following points:

1. Note the position of gas tap from service, so that it can be set at *same* place when another test is made, and adjustment of the rate avoided.
2. See that sulphur burner has a non-luminous flame.
3. Try the shutting-off mechanism on clock, and see that the wire stops the pendulum. The wire being necessarily slight, it is liable to become bent, so that it does not exert sufficient pressure on the pendulum. It can easily be adjusted before a test is made.
4. See to water-line of meter. The meter should be tested by the $\frac{1}{4}$ -cubic-foot measure in the manner described in par. 138 *et seq.*

The gas service is so arranged that when this is done the gas can pass into the 3-way cock at back of meter without going through the SH_2 glass and ammonia saturator. If the service tap has three ways, and a by-pass is arranged at inlet of meter, this can be effected. The above instructions apply to the Metropolitan Testing Stations, and are to a great extent based upon those issued by the Referees. Where companies have not the same statutory obligations it will probably be found advisable to adopt the same arrangement, which is certainly simple and efficient.

323. The operation which now remains to be described is the analysis of the products of the combustion of the sulphur compounds other than SH_2 . After each testing the Aerorthometer is read and the height of the two mercury columns, as they stood when the tap was shut off, noted. (See pars.

331, 332.) The flask or beaker which has received the liquid products of combustion of ten cubic feet of gas is emptied into a measuring cylinder, and then replaced to receive the washings of the condenser. Next the trumpet-tube is to be removed and well washed out into the measuring cylinder. The condenser is then to be flushed twice or thrice by pouring quickly into the mouth of it forty to fifty cubic centimetres of distilled water. These washings are brought into the measuring cylinder, whose contents are to be well mixed and divided into two equal parts. A *decigallon* and a half-*decigallon* flask, each with one mark on neck and stoppered, are convenient measures.

324. One-half of the liquid is to be set aside, in case it should be desirable to repeat the determination of the amount of sulphur which the liquid contains. This portion is to be examined under the same conditions as have been prescribed for the examination of the second portion of the liquid obtained from the apparatus used in testing for ammonia; unless thus previously used, it is to be preserved, in a bottle properly labelled, for one week.

325. "The remaining half of the liquor is to be put into a beaker (Fig. 47), covered with a large watch-glass, . . . treated with hydrochloric acid sufficient in quantity to leave an excess of acid in the solution, . . . and then raised to the boiling-point, but not so violently as to occasion loss by spurting. The hydrochloric acid should be used in a diluted condition—one part strong acid to four or five parts of water. The presence of an excess of acid in the liquid will be shown by the complete absence of effervescence in the last additions, and by the application of a litmus test-paper, which will change colour from blue to a distinct red colour. An excess of a solution of barium chloride is now to be added, and the liquid again boiled for five minutes." The solution of barium chloride consists simply of the chlo-

ride dissolved in distilled water in the proportion of about ten grains of chloride to the ounce of water. A little experience will soon satisfy the operator in respect to *an excess*. If a saturated solution of the chloride be made it will be sufficient to add 4 cubic centimetres of such solution to the boiling liquid, as there will then be an excess of the BaCl_2 solution, provided the sulphur in the gas is not greatly in



FIG. 47.—BOILING LIQUID IN BEAKER.

excess of the maximum quantity (par. 306). In fact, the BaCl_2 salt contained in 4 cubic centimetres of the saturated solution will be sufficient to precipitate barium sulphate from liquid containing the equivalent to about 35 grains sulphur per 100 cubic feet of gas.

326. "The vessel and its contents are to be allowed to stand till the barium sulphate settles at the bottom of the vessel, after which the clear liquid is to be, as far as possible, poured off through a filter paper. The remaining liquid and barium sulphate are then to be poured on to the filter, and

well washed with hot distilled water." The paper must be free from impurities, and a piece about four inches in diameter when burned by itself in crucible to whiteness should not produce more than 4-100ths of a grain of ash. The filter should be first wetted with distilled water from a wash bottle. If when transferring the solution to the filter a glass rod moistened with distilled water is brought into contact with the vessel from which the liquid is poured, it will prevent the last drops from running down the outside of the vessel. The vessel and rod are then washed out with distilled water, which washings are added to the rest of the liquid. (Fig. 48.)

327. The washing of the filter (Fig. 49) is effected by ap-



FIG. 48.—POURING OUT LIQUID.

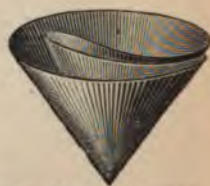


FIG. 49.—FILTER PAPER, FOLDED.

plying the lips to the pipe of the wash-bottle (Fig. 50) and blowing a gentle stream of hot water from the pipe upon the filter. In washing a precipitate in a filter (Fig. 51) the stream of water should be directed upon the upper edge, so as to wash down the particles, which have a tendency to accumulate there as the solution rises under the influence of capillary attraction. The stream of water should first be directed to the filter funnel itself, as first contact of the water with the filter paper may bore a hole through latter. "In order to ascertain whether every trace of barium chloride

and ammonium chloride has been removed, a small quantity of the [latest] washings from the filter should be [received direct from the funnel] in a test-tube, and a drop of a solution of silver nitrate or dilute sulphuric acid added; should the liquid, instead of remaining permanently clear, become cloudy, the washing must be continued until on repeating the test no cloudiness is produced." The silver solution is made with silver nitrate dissolved in pure distilled water, in about the proportions of five grains of nitrate to the ounce of water. It may be kept ready for use in a stoppered bottle.

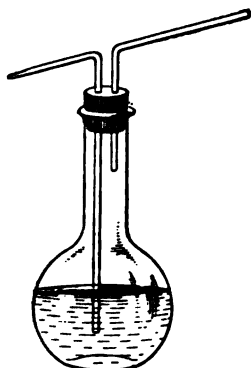


FIG. 50.—WASH-BOTTLE.



FIG. 51.—FILTER IN STAND.

Silver nitrate solution will show both chlorides, but dilute sulphuric acid will only show the presence of the former. Dry the filter-paper and its contents by placing the funnel containing the filter on a stand, upon a piece of wire gauze over the rose burner, or place in an oven or hot closet. When quite dry remove the filter carefully from the funnel, so as to lose none of the precipitate, "and transfer it to a weighed platinum crucible."

328. Place the platinum crucible (the weight of which has been accurately determined in a sensitive balance, and recorded) upon a sheet of clean, smooth, and, if

possible, *dark*-coloured paper. Hold the filter over the crucible and unfold it. Bring the edges of the filter-paper together, so as to form a sort of bag with the powder inside. With a gentle rolling action move the top of the bag to and fro. The powder will become detached from the paper, and must be transferred as completely as possible to the crucible. Refold the filter into a small parcel, tie round with a thin platinum wire, ignite, and let the ashes fall into the crucible. Transfer any spilled particles of the powder to the crucible.

329. "Heat the crucible over a lamp [a Bunsen gas burner without the rose head], increasing the temperature gradually from the point at which the paper begins to char up to bright redness. When no black particles remain allow the crucible to cool; place it when nearly cold in a desiccator over strong sulphuric acid (to prevent absorption of moisture), and again weigh. The difference between the first and second weighings of the crucible will give the number of grains of barium sulphate. Multiply this number by 11 and divide by 4, the result is the number of grains of sulphur in 100 cubic feet of the gas."

330. The reason for this calculation is as follows: Every grain of BaSO_4 contains 0.13734 of a grain of sulphur, and half the liquor and washings from the quantity of gas burned (10 feet, half of which is 5) having been operated upon, the above quantity is multiplied by 20 to determine the sulphur in 100 cubic feet of gas.

$$0.13734 \times 20 = 2.7468,$$

which is equivalent to multiplying by 11 and dividing by 4, as, $\frac{11}{4} = 2.75$. In this way the quantity of sulphur per 100 feet is easily calculated from the weight in grains of barium sulphate precipitated.

331. This number is to be corrected for the variations of

temperature and atmospheric pressure by finding the mean of the Aerorthometer readings taken at the beginning and at the end of any testing (see pars. 321 and 323). The reading at the beginning of the testing is to be made by the gas examiner, who before leaving the testing place will set the columns of mercury level in the two tubes of the instrument and will connect the lever-tap of the Aerorthometer with that of the meter. The fall of the lever of the meter will release a similar lever turning a tap, which closes the tube of the Aerorthometer. The reading of the Aerorthometer as it stood at the end of the testing will require a small correction for the difference in level of the mercury in the two tubes, which is to be made in the following manner:

332. Let R be the corrected reading, r_1 the actual reading of the Aerorthometer (the closed tube), r_2 the reading of the companion tube, h the mean height of the barometer in units of the Aerorthometer scale, a figure which will be printed on each instrument.

Then

$$R = r_1 \times \frac{h + r_1 - r_2}{h}.$$

The correction by means of the Aerorthometer reading may be made most simply and with sufficient accuracy in the following manner:

When the Aerorthometer reading is between .955-.965, .966-.975, .976-.985, .986-.995, diminish the number of grains of sulphur by 4, 3, 2, and 1 per cent., respectively.

When the Aerorthometer reading is between .996-1.005, no correction need be made.

When the Aerorthometer reading is between 1.006-1.015, 1.016-1.025, 1.026-1.035, increase the number of grains of sulphur by 1, 2, and 3 per cent., respectively.

The mean of R and the reading at beginning of test is the "Aerorthometer reading" for the purpose of this correction.

Example:

Grains of barium
sulphate from 5
cubic feet of gas 4.3
Multiply by 11 and
divide by 4

Aerorthometer
reading 1.018

4)47.3

Grains of sulphur
in 100 cubic feet
of gas (uncor-
rected) 11.82
Add $11.8 \times \frac{1}{100} =$.24

Result :
12.1 grs.

Grains of sulphur
in cubic feet of
gas (corrected). 12.06

The Aerorthometer reading is the reciprocal of the tabular number. The gas examiner shall, not less often than once a month, compare the Aerorthometer reading with the reciprocal of the tabular number deduced from observations of the barometer and thermometer, and if there is a difference of more than one-half per cent., the instruments are to be readjusted.

333. *Taplay's Sulphur Correction Tables.*—The calculation by above formula is a little tedious. It can be very greatly reduced by the use of the tables (Appendix M) devised by Mr. J. G. Taplay, and now published for the first time. It will be seen from the explanation accompanying the tables that the calculation is thereby reduced to a minimum.

334. Where the barometer and thermometer are used instead of the Aerorthometer, proceed as follows:

Find tabular number by referring to Table D, Appendix.

When the tabular number is between 955-965, 966-975, 976-985, 986-995, increase the number of grains of sulphur by 4, 3, 2, and 1 per cent. respectively.

When the tabular number is between 996-1005, no correction need be made.

When the tabular number is between 1006-1015, 1016-1025, 1026-1035, diminish the number of grains of sulphur by 1, 2, and 3 respectively.

The mean readings of barometer and thermometer at beginning and end of test are taken for the purpose of finding the tabular number.

Example:

Grains of barium sulphate from 5 cubic feet of gas.	4.3	Barometer (mean)...	29.4
Multiply by 11 and divide by 4.		Thermometer (mean)	58
		Tabular number....	985

4)47.3

Grains of sulphur
in 100 cubic feet
of gas (uncor-
rected) 11.82
Add $11.8 \times \frac{1}{100} =$ 1.24

Result:
12.1 grs.

Grains of sulphur
in 100 cubic feet
of gas (correct-
ed) 12.06

335. If a desiccator be used for the purpose mentioned in par. 329 it may consist of a small porcelain pan, having a few upright partitions in it to support the crucible and a bell cover. Strong sulphuric acid is then poured into the pan and the crucible placed upon the top of the partitions, and the pan finally covered by the bell glass. When cold, the weighings should be conducted with promptitude, and in a dry place.

336. As the Referees' rule for calculating quantity of sulphur per 100 cubic feet of gas only applies to the products resulting from the combustion of exactly 5 cubic feet (half the quantity obtained in the combustion of 10 cubic feet of

gas), it is needful to state that 233 parts by weight of barium sulphate contain 32 parts of sulphur, or

$$\frac{32}{233} \text{ parts} = 0.13734$$

parts of the whole. Hence, if any other quantity of liquid than that due to 5 cubic feet of gas be operated on, the weight of sulphur in that quantity of gas will be found by multiplying the weight of sulphate obtained by 0.13734 and then by proportion finding the number of grains per 100 cubic feet.

337. The chemical reactions upon which the analysis for sulphur, as described, depends are as follow: Gas contains *hydrogen*, *carbon*, and *sulphur*, which in the process of combustion combine with the *oxygen* of the atmosphere, and form *water*, *carbon dioxide*, and *sulphurous acid*, the last being speedily oxidised more or less completely into *sulphuric acid*. *Ammonia* being present, the acids unite with it, *ammonium carbonate* and *sulphate* being formed, which are carried down in solution by the condensed *water of combustion*.

Barium chloride decomposes both *ammonium carbonate* and *ammonium sulphate*, the acids of those salts uniting with the *barium* of the *chloride* to form *barium carbonate* and *barium sulphate*, while the *chlorine* of the *barium chloride* unites with the *ammonium* (H_4N) of the *ammonium carbonate* and *sulphate* to form soluble *ammonium chloride*. In order to avoid the precipitation of *barium carbonate* with the *barium sulphate*, the liquid is acidulated with hydrochloric acid, and boiled, so as to drive off all carbon dioxide and completely unite the ammonium which at first was in solution as *carbonate* with the hydrochloric acid, so as to form the other soluble salt, ammonium chloride. Finally, the barium solution is used to decompose the am-

monium sulphate, and give a precipitate of insoluble barium sulphate.

338. All the chemicals employed must be of the purest description. If it is deemed needful to test any samples, the requisite information will be found in chemical text-books.

339. Various alternative methods of condensing the products in the sulphur test and arresting the ammonia have been devised, but the above described methods are generally used for official tests. Several short tests are described in Chapter 8, such as the Harcourt tests, the Wanklyn method, *etc.*

[NOTE.—Pars. 340-349 are left blank to facilitate additions in a future edition.]

CHAPTER VI.

COAL TESTING.

350. To the gas-maker the value of coal depends upon the yield of gas and bye-products as determined by an experimental plant, or practical trial. He may, however, wish to obtain a proximate analysis, and the best-known means are described below.

Estimation of Moisture.—At a determined temperature an approximate estimate of the moisture lost may be taken by drying a sample of coal at 212° Fahr. Finely powder a convenient quantity—say, two or three grams of coal—place same between two watch-glasses, weigh, and note. Then dry in a water drying oven at a temperature of 212° Fahr. Weigh every two hours, and note weight. The lowest weight should be taken, and the moisture is represented by the difference between this and the original weight. An increase may be observed in some of the weighings, due to oxidation. Therefore, the lowest weight is taken, and this test can only be looked upon as an approximate one.

351. A better method for the estimation of moisture in coal is to pass gas (being dried in the process) through, firstly, a weighed stoppered U tube in which is placed a finely powdered and weighed sample of coal, this U tube being suspended in a beaker of water which is kept boiling; and secondly, through another U tube filled with calcium chloride (free from alkali and carefully weighed) to the outlet of which is connected a small calcium guard tube, at the

outlet of which the gas is burned in a small jet. The gas is passed through the series for two or three hours, during which time the moisture should have been removed from the coal in the U tube and deposited in the weighed calcium tube. These two being weighed before and after the test, the amount of moisture is directly ascertained. It is well to reconnect the series and let the gas pass for a short time after the second weighing and then to weigh again, so as to ascertain if the absorption in the first test was complete.

352. *Estimation of Volatile Matter and Coke.*—The best method is perhaps that of Mr. Lewis T. Wright. Take two grams of very finely powdered coal, and spread evenly at the bottom of a thin platinum crucible. Weigh this without the cover. Then place it, having put on the cover, over a Bunsen burner flame. About one minute after gases have ceased issuing from the lid the crucible is removed from contact with the flame, placed in a desiccator to cool, and then weighed without the cover. The difference in weight shows the volatile matter, the balance (which can be observed if weight of crucible is known) being coke. This is a fairly constant test if the gas flame is of the same height and the crucible placed in the same position over it for each test. It should be noted that if accurate comparative results of any test are required in a laboratory, the same standard should be observed in each case. The two tests described above are cases in point. The first requires a fixed temperature at which moisture is estimated, the second a fixed or constant amount of flame upon the crucible.

353. *Estimation of Ash.*—Clean, ignite, cool in a desiccator, and weigh a platinum boat, and note weight. Finely powder a fair sample of coal, place two grams in a boat, weigh, and note. Now put boat and contents in a piece of combustion tube about two feet long and sufficiently large to take the boat and a piece of platinum

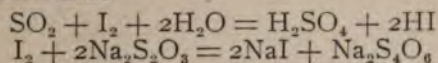
foil, upon which it should rest. Let the boat rest, say, six inches from the open end of tube. Close other end and connect with an aspirator. Place tube over a combustion furnace, and draw by means of the aspirator a gentle current of air through it. Keep the temperature as high as possible without fusing the glass. When the combustible matter seems to have been burned, turn off burners of furnace, and remove the boat and its contents as soon as possible, weigh, and note. Replace boat and contents in combustion tube, and place over furnace again, and heat for about fifteen minutes. Proceed as before, and weigh. If the weighings coincide, the test is complete, and the weight of ash can be found; but if not, the combustion is not complete, and the test must be repeated until two consecutive weighings coincide. The sample of ash can be kept for determination of the sulphur in same.

354. *Estimation of Sulphur in Coal.*—Nakamura's method is generally used, and is most accurate. Take a small sample of coal, and very finely powder. Weigh with care two grams, mix with four times its weight of fusion mixture (ten parts anhydrous sodium carbonate and thirteen anhydrous potassium carbonate). Place in a platinum crucible, partly cover, and heat very gently with a spirit flame. The whole principle of this test depends upon care in heating, as no smoke or smell must be observable during its progress. The instructions on this point must, therefore, be carefully followed. The heat is maintained for, say, two hours, when the crucible should be slightly red and the surface of the contents faintly gray. Now raise the temperature to redness, and let it so remain for about forty-five minutes. Let crucible cool, and then immerse it in a beaker of distilled water, covered with a watch-glass, and gently heat, so that the white mass remaining will become detached. Remove empty crucible. Filter the contents of beaker, add

a few drops of bromine, and boil to expel excess of same, and acidify with HCl. Precipitate the BaSO_4 with barium chloride in the usual manner (par. 325 *et seq.*). From the weight of BaSO_4 the weight of sulphur is found by multiplying by the usual factor, 0.13734, and a percentage calculation on the amount of coal originally weighed can then be made. Be careful in handling the filtrate and washings, so as not to lose any of the residue after the heating. Be careful with the application of gentle heat, so that no smoke or smell (which would probably mean loss of sulphur) is given off. The sulphur in coke is estimated in the same way, and is deducted from the sulphur in coal in order to give the amount of volatile sulphur in coal (see par. 365), which is what the gas-maker ought to know.

355. *Estimation of Volatile Sulphur in Coke.*—Weigh out a quantity of coke equal to a known weight of coal and roast in a combustion tube in the manner described in par. 354, but place ten cubic centimetres of standard solution of iodine in a bulbed U-tube between the combustion tube and the aspirator. When combustion is complete, ascertain the amount of free iodine in the solution by titration with standard sodium thiosulphate solution. The iodine remaining in the solution is found by the titration, the amount acted upon by the SO_2 being obtained by difference, and the weight of S calculated from this.

The equations are :



The standard solutions can be obtained already prepared, or their method of preparation can be found in Sutton's Volumetric Analysis.

356. *Estimation of Sulphur in Ash.*—It may sometimes be required to make this test. Weigh about 20 grains of ash and digest with dilute HCl, to which a few drops of bromine

have been added, excess of bromine being expelled by heating. Precipitate the sulphur in the manner described in par. 325 *et seq.* (See par. 365.)

357. *Estimation of Hydrogen, Carbon, Nitrogen, and Oxygen in Coal.*—Where it is desired to ascertain the elementary composition of coal a combustion can be made. Two combustions are necessary, in one of which the H and C are taken up by CaCl_2 and potash, respectively, while the other, the N, is taken by H_2SO_4 , and the oxygen is found by difference.

358. The combustions are effected on a furnace, and for the first a combustion tube about thirty inches long and one-half inch in diameter is taken, and one end sealed. A sample of coal being finely powdered, four or five grains are weighed out and well mixed with hot chromate of lead. Sufficient chromate is required to fill the combustion tube within, say, four inches of its mouth, where some copper turnings are pressed. See the tube is well packed, and place it in the furnace, letting the open end project about one inch. Fill a calcium chloride tube with granulated CaCl_2 , free from alkali, carefully weigh, and note weight. Take some potash bulbs, fill the lower part with strong (sixty per cent.) potash solution (the potash being free from carbonate), close ends of tubes, weigh carefully, and note weight. Now attach the inlet of CaCl_2 tube to the combustion tube, and the outlet joint by a short piece of india-rubber tube to the potash bulbs. See that the connections are tight, start combustion, which must be gradual, and the cocks of furnace enable this to be so effected. See that the tube becomes dull red along its whole length. When the bubbles have ceased passing through the potash bulbs, draw air through the combustion tube in the usual manner, having unsealed the closed end of the tube, so that all the CO_2 and moisture are drawn into the bulbs and tube. Disconnect, and

when cold weigh both the CaCl_2 tube and the potash bulbs. The gain in the former is due to water, from which the hydrogen is calculated, and in the latter to CO_2 , from which the carbon is calculated. As an example, suppose 5 grains to be weight of coal taken, and the CaCl_2 tube gained 3 grains and the potash bulbs 14 grains.

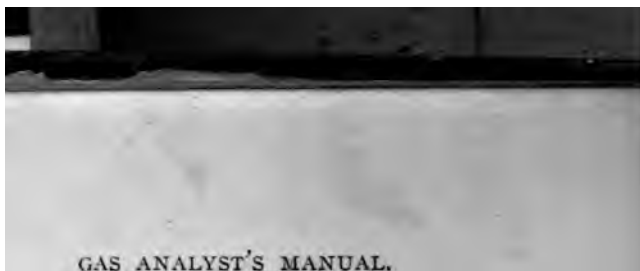
The equation for percentage of hydrogen is:

$$\text{As } 5 : 100 :: \frac{3 \times 2}{18} : x \quad x = 6.6$$

The equation for percentage of carbon is:

$$\text{As } 5 : 100 :: \frac{14 \times 12}{44} : x \quad x = 76.36$$

359. To ascertain the nitrogen it is necessary to make a combustion as above, but using soda-lime in the combustion tube, with about ten grains of the powdered coal, and aspirating over bulbs with dilute H_2SO_4 (ten cubic centimetres of normal H_2SO_4 with distilled water added). We will assume 10 grains of coal were used. After combustion is complete filter the contents of bulbs, make up with distilled water to, say, 100 cubic centimetres, having coloured with a few drops of cochineal. Take some standard solution of caustic soda of such a strength that 3 cubic centimetres neutralise 1 cubic centimetre of the acid solution. The amount required would be 10 cubic centimetres of standard soda solution diluted to 300 cubic centimetres. Now titrate, and note amount of caustic soda solution used to neutralise. Say this is 60 cubic centimetres; then 2 cubic centimetres of the standard H_2SO_4 placed in the bulb have been taken up, the remaining 8 cubic centimetres having been neutralised by the ammonia evolved from the combustion. Now, .017 grains of $\text{NH}_3 = 1$ cubic centimetre of standard H_2SO_4 , and 1 grain of NH_3 contains $\frac{1}{4}$ of N; hence, percentage of nitrogen present equals



$$\frac{.017 \times 8 \times 14 \times 100}{17 \times 10} = 1.12 \% N.$$

360. The percentage of oxygen in the coal is found by adding the amounts of C, H, and N, and deducting from 100. Thus, in the imaginary sample of which a combustion has been made, the proportions are:

Hydrogen.....	6.6
Carbon.....	76.36
Nitrogen.....	1.12
Oxygen.....	15.92

361. *Specific Gravity of Coal.*—This is taken in the manner usual for ascertaining the specific gravity of a solid—namely, by weighing a sample in air, weighing the same in water, and dividing the former by the difference between the two, the result being the specific gravity of coal compared with water, which is taken as having a specific gravity of 1 at 60° Fahr. When weighing in water, the sample is suspended from the specific gravity pan of the balance into a beaker of distilled water. The sample should be brushed free from loose particles, and it must be seen that no bubbles are on the surface of the coal when the weight is taken. The specific gravity enables one to ascertain the space a given quantity of coal would occupy.

362. *Experimental Test.*—In addition to the laboratory tests described above, it is useful and convenient to make a working test on a small scale of a sample of coal, so as to ascertain the illuminating power, the yield of gas per ton, the weight of coke per ton, and, where possible, the quantity of the liquor. This is done by means of a small experimental plant. These plants are usually made to take a charge of 2.24 lbs. (the $\frac{1}{100}$ th part of a ton), and this is converted into gas in a small retort, passed through a condenser and purifiers, and into a holder with a graduated scale. In some cases a

washer and a scrubber are used, and instead of a finely graduated holder, one to act as a receiver only, the gas being measured by passing through a meter first. There is, however, no standard pattern, the idea simply being to reproduce a gas works on a small scale. Different arrangements of experimental plants are described and shown below. The results given on a small plant of this kind are rather higher than would be obtained in practice. It is usual when the illuminating power is ascertained to find out the value of the coal in pounds of sperm per ton or candles per ton.

363. The standard sperm candle burns $1\frac{1}{8}$ pounds (120 grains) of sperm per hour, and the candle-power is always expressed as that of gas burning at the rate of 5 cubic feet per hour. Therefore, the yield per ton (as found from the experimental run), multiplied by the illuminating power in standard candles, and divided by 5, will when multiplied by $1\frac{1}{8}$ give the value of a ton of coal in pounds of sperm.

Example:

Yield from 2.24 lbs. = 10 cu. ft. = 10,000 ft. per ton;

Illuminating power = 17.5 candles;

then $\frac{10,000 \times 17.5 \times 3}{5 \times 175}$ = value of a ton of coal in pounds of sperm = 600.

364. With an experimental plant there is frequently an amount of trouble caused in cleaning same out after a run. It should, therefore, always be seen that the design submitted by a maker is constructed with this point in view, all ends being provided with plugs and cocks, etc., to facilitate this. The pipes should always be cleared of air before commencing a run (by emptying the holder of the remainder of its last charge through the apparatus), and the holder need not be weighed to exhaust the make of gas; if it is balanced, it will be found to be sufficient. The volume of gas must be corrected for thermometer and barometer,

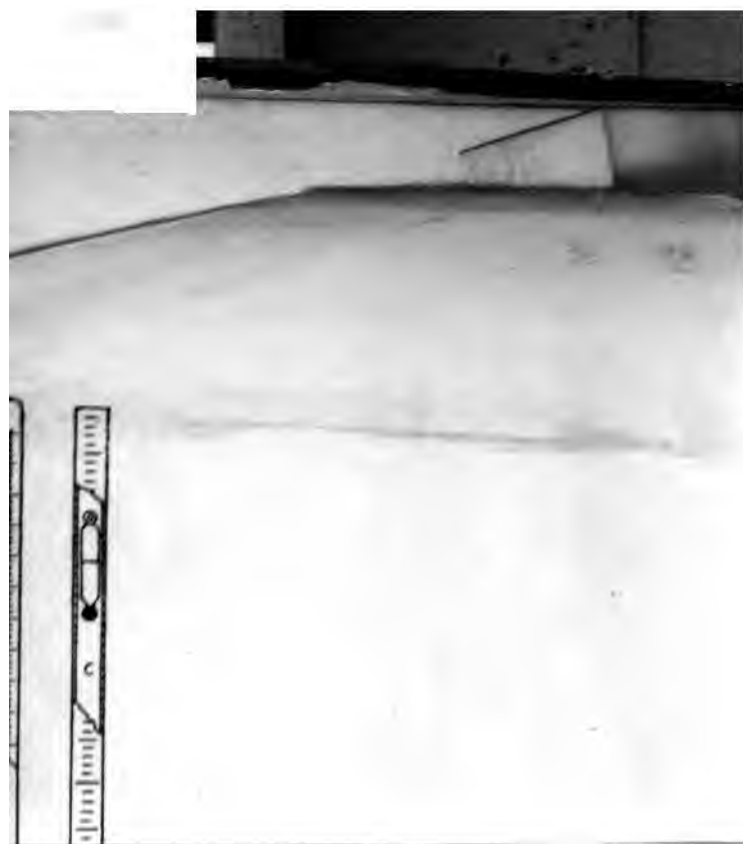
which should be observed and recorded. The coke must be kept, allowed to cool, weighed, and preserved, if test for sulphur is to be made. There will not be, as a rule, sufficient liquor after one experiment to test; therefore, if several experiments are made with the same quality of coal, it can accumulate, be tested and calculated in proportion. (See Chapter 9.)

365. From this chapter we have particulars for making the following tests of coal, which it is convenient to enter upon a printed form, and a record thus kept.

1. Moisture in coal, percentage.
2. Volatile matter and coke, "
3. Ash in coal, "
4. Sulphur in coal, "
5. Sulphur in coke, "
6. Volatile sulphur in coal (amount in coal less amount in coke and ash).
7. Specific gravity of coal.
8. Coke, percentage by weight.
9. Yield of gas per ton.
10. Illuminating power.
11. Pounds of sperm per ton.
12. Gallons of liquor per ton. (This can be calculated by Wills's method, see chapter 9, and calculated to 10 oz. strength.)

The following makes the estimation and percentage record of volatile sulphur in coal clear: The volatile sulphur is that which is given off with the gas on destructive distillation of the coal, and therefore this is what it is required to know. First, the total sulphur in coal is found (par. 354). Then the fixed sulphur in coke, the quantity operated upon being the proportion of coke to the sample of coal in which the total sulphur was found (par. 354). This enables the percentage of sulphur in sample of coal due to the coke to be deducted. Then the sulphur in ash, the quantity operated upon being also proportioned so that this amount can be de-

ASTOR, LENOX & TILDEN FOUNDATIONS



ted (par. 356). The remainder is volatile sulphur in . . . If proportional amounts of coke and ash are not taken must be reduced to the proper percentage.

56. Fig. 52 shows a coal-testing plant designed for the distillation of 2.24 lbs. ($\frac{1}{1000}$ th part of a ton). The coal is heated in an iron retort packed with fireclay and heated by . . . and passes up a standpipe, at the upper end of which is a plugged tee, and in which a nitrogen bulb thermometer is placed. The gas then passes through a condenser, which consists of a coil of $\frac{3}{4}$ -inch barrel, each bend of which is angled, so as to facilitate cleaning, and then into a washer-bubbler arranged with removable trays of coke, and with a water spray which meets the gas as it travels up the tower. The bottom of the washer is furnished with a pipe, the open end of which dips into a vessel where the tar and oil are collected. From the outlet of the washer the gas passes through a small cast-iron purifier, $15'' \times 15'' \times 18''$, lined with three removable wood grids and with a cast-iron water luted cover, the gasways being arranged as on a standard purifier. The apparatus is provided with thermometers at various points and pressure gauges, so that its work can be checked.

57. The gas passes from the outlet of the purifier either directly into a suitable holder where it can be stored or measured, or through an arrangement of coupled meters, so connected that one-half is blown away and the other half measured, registered, and passed into a holder for storage. The whole of the apparatus can be set up in a small space, either on a brickwork or wooden platform or upon the ground, so that it affords every facility for experimental testing and is easily cleaned.

58. It may be desired, however, to test a larger sample of coal, and the apparatus shown in Fig. 53 is designed for this purpose and for use where a sample of coal is placed in a

single retort in an ordinary setting. The condenser consists of an arrangement of $1\frac{1}{2}$ -inch iron barrel with plugged connections at top and bottom, and can be arranged so that sec-

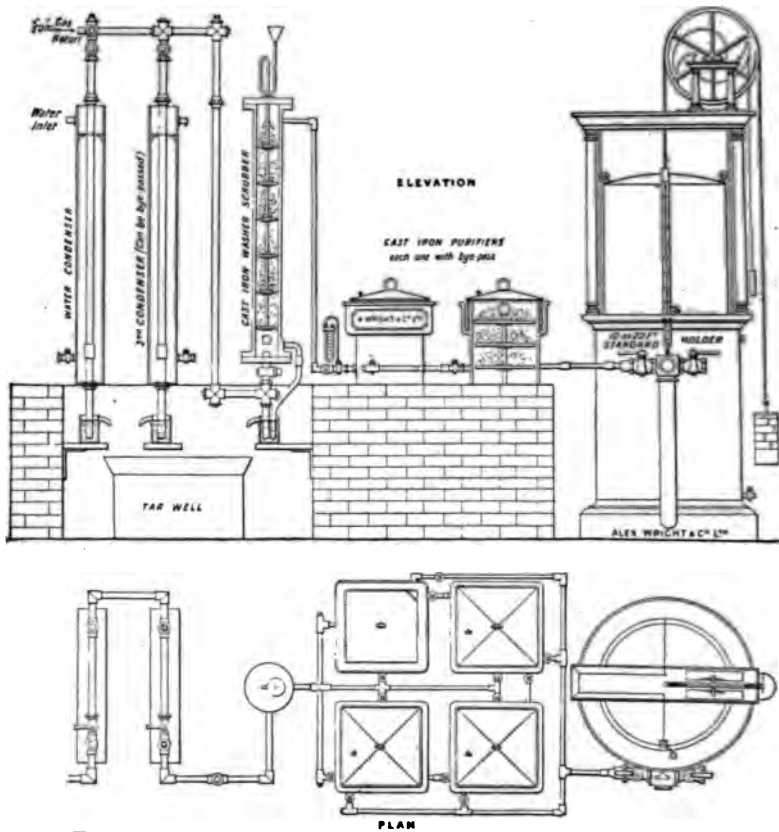


FIG. 53.—COAL-TESTING PLANT FOR CHARGES UP TO 1 CWT.

tions only can be used, and the rapidity and degree of condensation thus regulated either to a point where best results are obtained, or until the actual working conditions on the gas works are reproduced. The condensers can be surmounted (as can the coil used in the small set described

above) by a water pipe with cocks and jets, so that cold water can play on the whole of the pipes or on any section, while if the necessity to use heated water is contemplated the coils can be placed in tanks the water in which can be heated. The bottom bends of this condenser, and also the small condenser, can be provided with a dip pipe sealed by the tar- and liquor-collecting vessel.

369. The gas passes from the condenser to the washer-scrubber, which is of cast iron and arranged similarly to the one described above, but of a suitable capacity for a larger volume of gas. It then passes to the purifiers, which are like the one illustrated in Fig. 52, but arranged in a set of 4, so connected that any one can be cut out or they can be used in any combination. This affords facilities for the trial of different purification materials without trouble. The gas at the outlet of the purifiers is treated in the same way as in the small set. The apparatus is provided with every facility for cleaning, while separating vessels and a tar tank are also used.

370. It may sometimes be desired to examine coal or coke from another point of view—namely, its calorific power. This is usually done in this country by Lewis Thompson's Fuel Test, which is a simple technical apparatus requiring only care in its manipulation. There are many other forms of solid-fuel calorimeters, to which passing reference is made in Chapter IV, but it is deemed advisable to describe only this form here, seeing that practised chemists have found it to yield results which agree very narrowly with those obtained by scientific investigation in the laboratory. It may be required to make two records by this apparatus.

- (1) The calorific power of the fuel in calories.
- (2) The evaporative power of the fuel in pounds.

371. (a) The "*calorie*" for this purpose may be defined

as being the "*gramme-calorie*," viz., the amount of heat required to raise 1 gramme of water 1° Centigrade.

This calorie is the one-thousandth part of the "*calorie*" used in expressing heat value of gases.

(b) The "*evaporative power in pounds*" is "*the number of pounds of water at 212° Fahrenheit that can be evaporated or converted into steam by 1 pound of fuel.*"

(c) The "*latent heat of steam*" is 967 heat units (B. T. U.). The above definitions will be made clearer by reference to Chapter IV, but assuming them to be correct, the plan or principle of the Thompson calorimeter which follows will be intelligible.

372. *Evaporative Power*.—If we heat 967 parts of water 1° Fahrenheit, we have employed as much heat as would have boiled off one part of water from 212° Fahrenheit; if the same quantity were raised 10° Fahrenheit, we have used enough heat to boil off 10 parts of water, and so on. Now, if we burn 1 gramme of coal in 967 grammes of water, and note the rise in temperature of same, it is evident that the number of *Fahrenheit* degrees is equal to the number of grammes of water which a gramme of the coal would convert into steam from boiling-point, and we have the evaporative value of the fuel, because the weights of fuel burned and of water used being proportionate to the latent heat of steam, the indications of the apparatus are general, and the evaporative value of the coal can be expressed either as pounds of water boiled off by one pound of fuel or kilogrammes of water boiled off by a kilogramme of fuel. It is, however, the practice to use a *Centigrade* thermometer with this apparatus; therefore, in calculating the "*evaporative power*" the rise in temperature (plus 10 per cent. as compensation for specific heat of apparatus, etc.) must be multiplied by 1.8, which is the relation between Centigrade and Fahrenheit scales, and the result will be the evaporative power of the

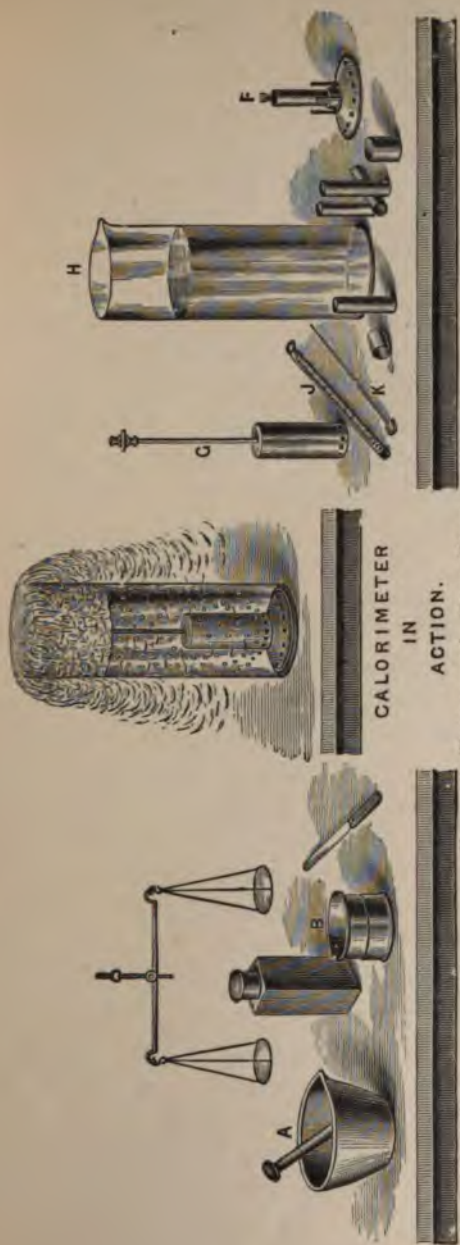


FIG. 54.—THOMPSON'S FUEL TEST IN ACTION.

fuel at 212° Fahrenheit either in pounds water per pound fuel or in kilogrammes water per kilogramme fuel.

373. *Calorific Power*.—To find the value of coal which has been burned in water in the proportion of 1 to 967, we must multiply the degrees *Centigrade* through which the temperature has been raised (plus 10 per cent. as compensation for specific heat of apparatus, etc.) by the relative quantity of water used to quantity of fuel burned, viz., 967.

374. It will be clear from the above that the apparatus must be made so that the heat imparted to 967 units (or a multiple) is measured. And, as a matter of fact, the water vessel shown at *H* in Fig. 54 is graduated at (967×2) 1934 grammes, and as a rule 2 grammes of fuel are operated upon.

To Make a Test.

375. Select from a mass of the coals to be tested several portions which collectively will fairly represent an average sample, and reduce to a powder fine enough to pass through a wire gauze of 64 meshes to the square inch. Mix the mass, and then take from it about 20 grammes, which triturate in an *iron mortar*, *A*; when partly reduced separate the coarser particles from the completely reduced portion by means of the sieve, *B*, provided; the latter or fine portion being caught on a sheet of paper. Return the coarser particles to the mortar, triturate again, sift, and so on, until the whole mass has been passed through the meshes of the sieve. Intimately mix the powdered fuel and weigh out 2 grammes. The oxygen needful for the combustion of the fuel is furnished by a mixture consisting of 3 parts of chlorate and 1 part of nitrate of potash (each of the purest quality), reduced to a tolerably fine powder, so that it will pass through a gauze of 1000 meshes to the square inch, which powder when used must be *perfectly dry*. The two grammes

of powdered fuel to be tested are intimately mixed by means of a spatula with from 8 to 12 (some coals require more) times its weight of oxygen mixture; but with nearly all kinds of coal 11 times the weight of the coal, or 22 grammes of the mixture, will do well.

376. When the intermixture is seen to be complete, carefully introduce the resulting gray powder into one of the copper furnaces, and compress it down in successive small portions by means of a rammer or test tube with such degree of firmness as is required by the nature of the fuel. It is not well to compress by tapping the bottom of the furnace, because if this be done, the rougher portions of the oxygen mixture rise to the surface. The furnace is next placed in the socket of the brass plate; take about half-inch length of the fuse, and place on the top of the powder; avoid pressing, and use a wire to fill up the powder close to the fuse, as shown at *F*.

377. The glass cylinder, *H*, having been charged with 1934 grammes of water—that is, up to the engraved lines—take its exact temperature by means of delicate thermometer, *J*. As the temperature of a room is almost invariably much higher than the water-supply, a little hot water is added to that placed in the glass cylinder, until the difference of temperature between the water and the room is not more than 2 degrees.

This agreement between the water and air temperatures is (in the absence of any jacketing of the water cylinder) absolutely necessary.

378. Having the condenser cylinder, *G*, with its stop-cock closed, ready at hand, light the fuse of the charge, and at once cover it with the condenser, pressing the latter firmly upon the clutch springs of the brass base, and immediately submerge the condenser and base in the water contained in the glass cylinder. (See Fig. 54.) This operation must

be performed *quickly*, and *before the fuse ignites the mixture*, or the whole will be consumed in the air, and the experiment destroyed, besides which the operator will run the risk of having his hands and face seriously burned. After igniting the fuse and immersing the copper cylinder in the water, the apparatus should be kept in the best position for the gases to be evolved all around the cylinder, and the rate of combustion noted. Some coals are very unmanageable without practice, and samples of "patent fuel" are sometimes met with, containing unreasonable proportions of pitch, which require some caution in working and very close packing, inasmuch as small explosions occur, during which a little of the fuel escapes combustion.

379. As already said, many coals burn well with eleven times their weight of oxygen mixture, but according to the experience of some operators, there are coals which require as much as fourteen times their weight of the mixture. If the combustion proceeds with almost explosive violence, and is concluded in a very short time, it may be fairly assumed that the quantity of oxygen mixture present is too small, and larger quantities should be used in succeeding trials, until the best result is obtained, which should be confirmed by another experiment. (See example, par. 384.)

380. When combustion ceases open the stop-cock of the condenser, and if air does *not freely* issue, insert the long wire, *K*, to clear the pipe, then move the condenser several times up and down, which will cause the water within and without the condenser to acquire the same temperature. Blow away the smoke, and note the temperature indicated by the thermometer while its bulb is immersed in the water. The indications of a Centigrade thermometer should be read to one-twentieth of a degree, and of a Fahrenheit thermometer to one-tenth of a degree, otherwise the exact-

of an experiment will be impaired. As little as possible should elapse after the conclusion of combustion before the increased temperature of the water is ascertained. *As an average of ten per cent. of the heat generated from the fuel is absorbed by the instrument, this percentage must be added to every calorific result obtained.*

Examples:

Centigrade.

Temperature of water after combustion.....	22°
“ “ before “	15.5°
Degrees raised.....	6.5°
Add 10 per cent.....	.65°
Total	7.15°

Fahrenheit.

Temperature of water after combustion.....	73°
“ “ before “	60°
Degrees raised	13°
Add 10 per cent.....	1.3°
Total	14.3°

31. With regard to this 10 per cent. compensation it should be pointed out that each experimentalist has the means of obtaining the coefficient for his own apparatus, by weighing the different parts and by standard specific heat tables, expressing their weights in terms of water, adding the figure thus ascertained to the actual water used and making the multiplication of the number of degrees accordingly. The correction recommended is, however, sufficiently accurate for ordinary purposes, and approximates to the correction which would be necessary by eminent scientists.

32. In testing *coke*, *anthracite*, or other difficultly combustible substances, the *wide* furnace must be used, and the

mixture may be allowed to remain loose and uncompressed in the furnace, but in the case of *coal* the *narrow* furnace is required. When wax, spermaceti, and other fusible substances are tested, they require to be, in the first place, mixed or fused with about three times their weight of powdered peroxide of manganese or peroxide of copper, which serves to regulate combustion. If fusion be resorted to, the mass must, as with other fuel, be reduced to fine powder, and then mixed with the needful quantity of oxygen mixture. Sulphur requires no such provision, but may be burned safely with six times its weight of the oxygen mixture.

383. The fuse heretofore generally employed consisted of loosely twisted cotton cord, first steeped in a saturated solution of nitrate of lead, and then dried. Mr. Thomas prefers a quicker burning fuse, which is made by steeping Oxford cotton in a moderately strong solution of nitrate of potash. When dry it should burn a little too fast. To remedy this the cotton is rubbed between two pieces of cloth until it burns just freely enough, then four cotton strands are twisted together and cut into three-quarter-inch lengths. The furnaces must be well cleaned out before being reused. With some coals a strongly adherent mass is formed at the bottom of the furnace, and must be removed. The furnace must also be quite dry before being charged.

384. Example of two tests made by F. W. Hartley; sample taken, Welsh steam coal:

Grammes of oxygen mixture to two	
grammes of coal.....	22 and 26
Water raised in Centigrade degrees. .	6.63 and 7.27
Add 10 per cent. for loss by apparatus.	7.3 and 8.
Evaporative power (corrected temperature $\times 1.8$).....	13.14 and 144
Indicated power of fuel in calories (corrected temperature $\times 967$).....	7059 and 7736
Time of combustion in seconds.....	38 and 65

85. In a reproduction of an article in the *Chemical News*, Thomas, of Cardiff, says:

"In order to still simplify the calculations of the results, the following plan will, I think, commend itself to the authorities abroad who use the apparatus as a test to determine the calorific power of coal and Patent Fuel, which they have contracted for under a guarantee that it shall give a certain number of calories. Take 2 grammes of the fuel and mix intimately with 22 grammes of (11 times its weight) oxygen mixture. Have the glass cylinder graduated to hold exactly 2000 grammes (2 litres) of water, and use a Centigrade thermometer graduated into tenths of a degree from 0° to 35° .

86. "If after the combustion of 2 grammes of coal the thermometer registers 7.15 degrees (for it must be read to one-half tenth of a degree), this together with the one-tenth added to compensate for loss of heat by radiation, etc., will give 7.865. Now, the weight of water used was 1000 times the weight of the coal taken; hence, all that is necessary is to remove the decimal point 3 places to the right and we have at once the number of calories that the sample is equivalent to—namely, seven thousand eight hundred and sixty-five.

87. "I have recently got over the difficulty previously experienced in determining the evaporative power of patent fuel and of coals like cannel, which are rich in hydrogen without impairing the accuracy of the result. Good China clay (Kaolin) practically free from organic matter is ignited in order to get rid of moisture, water of combination, etc., and from .5 gramme to 1 gramme of the clay is added to the 2 grammes of coal and 22 grammes of oxygen mixture and thoroughly incorporated as usual. The China clay occupies considerable bulk and remains unaltered, but it very effectually retards the progress of the combustion and causes the mixture to burn with great regularity."

388. It should be stated that the apparatus is graduated to 2000 grammes as well as 1934, so that Mr. Thomas' system can be used.

[NOTE.—Pars. 389-399 are left blank to facilitate additions in a future edition.]

CHAPTER VII.

TESTING ENRICHMENT AND PURIFICATION MATERIALS.

400. In the previous chapter methods for the laboratory examination of coal were given by means of which an approximation of the commercial value of coals bought for gas-making or fuel purposes could be made. It is proposed in this chapter to describe means of checking the commercial value of light oils or evaporable hydrocarbons used for gas enrichment, of petroleum used in carburetting water gas, and for other methods of enrichment, and to give methods of examining lime, oxide of iron and Weldon mud. A method of estimating, by the Simmance-Abady Calorimeter, the calorific power of enrichment oils is also given (see par. 445), while a note on the chemical composition and testing of carburetted water gas is added.

LIGHT OILS OR EVAPORABLE HYDROCARBONS.

401. The actual value of light oils for enrichment can be found from the specific gravity, boiling-point (as a guide to careful distillation) and freedom from sulphur. The test for the latter is only made usually with benzol, which contains sulphur, and which is often used for enriching purified gas. The theoretical value and judicious use of light oils such as carburine, benzol, etc., depend upon a variety of considerations which have formed the basis of study by many

eminent experimentalists, and which are collated and summarised in an exhaustive series of articles in the *Journal of Gas Lighting* of from September 7 to October 26, 1897, inclusive. In that article the result of various experiments as to enriching values are tabulated, and they differ to a very great extent. It is, therefore, well that an actual experimental test be made in which the working conditions are reproduced and noted, such as illuminating power of gas to be enriched, temperature at which the gas is enriched, and proportion of enrichment material employed. It should always be borne in mind that the higher the vapour tension of the oil, or spirit, the greater will be the volume of vapour which the gas will carry permanently, and the proportion should always be kept well within the limits of saturation.

In making comparative tests, and in comparing records of other tests, the point as to *suitability of burners* (emphasised in par. 228) should always be kept in mind. Probably want of discretion in this direction is the reason for the great divergencies in published records.

402. *Gasoline* consists largely of pentanes, and has a specific gravity at 60° Fahr. of from .645 to .650. Its boiling-point is about 104° Fahr. The vapour tensions of its constituents are such that 10.7 per cent. of its vapour, by volume, saturates a gas at 32° Fahr.

Carburine consists largely of hexanes, and is extensively used. It has a specific gravity at 60° Fahr. of .680. Its boiling-point is about 160° Fahr. The vapour tensions of its constituents are such that about 8 per cent. of its vapour, by volume, saturates a gas at 32° Fahr., or 15.6 per cent. at 59° Fahr. One ton of it contains about 330 gallons, while 1 gallon equals about 30 cubic feet of vapour at 60° Fahr. Therefore, 1 gallon saturates about 190 cubic feet of gas at 60° Fahr.

Petroleum spirit (commercial benzoline or petroleum

phtha) is the fraction of American petroleum which boils from 175° to 225° Fahr., and has a specific gravity of from .695 to .705 at 60° Fahr. Its boiling-point is from 90° to 220° Fahr. The vapour tensions of its constituents are such that about 5 per cent. by volume of its vapour saturates a gas at 32° Fahr. One gallon equals about 26 cubic feet of vapour at 60° Fahr.

Distillate from residue of oil-gas compressing consists largely of benzene. It has a specific gravity of about .803 at 60° Fahr. One ton of it contains 279 gallons, and 1 gallon about 40 cubic feet of vapour.

Benzol (a product of coal tar) consists largely of benzene and toluene. The variety generally used is known as 90 per cent. benzol. At least 90 per cent. of it should distill at 212° Fahr. Its specific gravity at 60° Fahr. is about .882. Its boiling-point is about 176° Fahr. The vapour tensions of its constituents are such that about 2.7 per cent. by volume of its vapour saturates a gas at 32° Fahr., or about 7 per cent. at 59° Fahr. One ton of it contains about 254 gallons, and one gallon contains about 40 cubic feet of vapour at 60° Fahr. Therefore, 1 gallon saturates about 570 cubic feet of gas at 60° Fahr.

403. *Specific Gravity*.—The specific gravity of light oils may be found by means of the specific gravity bottle. The specific gravity can be observed also by means of a carefully graduated hydrometer with an open scale. In either case the test requires care and should be made at either 60° Fahr. or at 39.1° Fahr., at which temperature water is at its maximum density. The results should be recorded with the temperature. The method of using the bottle is as follows: Take a specific gravity bottle fitted with a well-ground glass stopper, weigh the same carefully and note weight; let this be *B*. Fill the bottle up to the mark on the neck with distilled water at 60° or 39°) recently boiled, dry the outside, weigh and



note weight, which will be that of bottle plus water; let this sum be W . Now empty bottle, drying it carefully inside by putting into it (after draining) a little alcohol, gently heating over a burner, the while blowing carefully through a tube about a foot long introduced into the bottle. When bottle is dry fill with the spirit or oil (at the same temperature as the water) up to the mark on the neck, dry outside of bottle, weigh and note weight, which will be that of bottle plus oil; let this sum be R . Then the specific gravity at

$$\times \text{degrees} = \frac{R-B}{W-B}.$$

The test should be made carefully and rapidly, and if it is not possible to weigh the oil at 60° Fahr. a correction must be made to that temperature by means of the coefficient of expansion, which is about 0.00036 per degree Fahrenheit (or 0.00065 per degree Centigrade) for petroleum oils.

404. *To find weight in pounds of a cubic foot of liquid multiply specific gravity by 62.425. To find number of cubic feet in a ton divide 35.9 by the specific gravity. To find number of gallons in a ton divide 224 by the specific gravity.*

405. *Enrichment Test.*—Seeing that the working method of light oil enrichment can generally be reproduced in a laboratory, the method of making this test will depend upon the apparatus at disposal. The description given below is of a test used by J. G. Taplay, of the Gas Light and Coke Co., and the apparatus is shown in Fig. 55. It will be seen that the arrangement can be made up independently of laboratory facilities, and connected up to the Photometer in any gas works.

406. The gas to be carburetted is tested first on the Photometer and its illuminating power recorded, together with the height of barometer, temperature and rate at which gas was consumed. In the arrangement shown in Fig. 55 the

gas can be bye-passed round the apparatus. A volume of the gas, say 5 cubic feet, then passes first through an experimental meter, where its rate is also measured, and enters the supply pipe, *A*, travels through pipes *B* and *C* to the three-necked Woulffe's bottle, *D*, which stands in a copper water bath, *E*, heated by the spirit lamp, *G*; from thence the gas

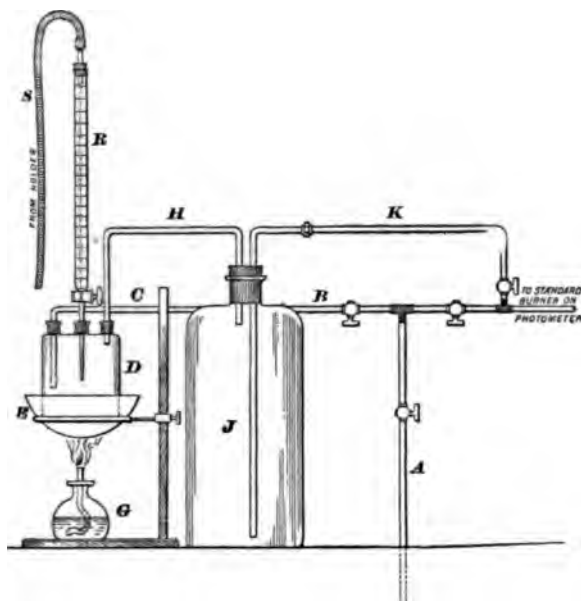


FIG. 55.—APPARATUS FOR TESTING ENRICHMENT POWER OF OIL (TAPLAY)

passes through the glass tube, *H*, to the large diffusing vessel, *J*, and then passes out by the brass tube, *K*, to the Argand burner, *M*. The Woulffe's bottle is about 12-ounce capacity, and the diffusing vessel about 100-ounce capacity. The Woulffe's bottle (stoppered with a cork) is also fitted with a 100 septem burette, *R*, fitted with a glass tap and ending in a fine capillary tube. The liquid hydrocarbon is poured into the burette and quantity noted and allowed to



run into the Woulffe's bottle drop by drop (about 1 drop in 6 seconds), and, being vapourised by the hot water, the hydrocarbon is carried over with the gas into the diffusing vessel and thoroughly mixed. The tube *S* is of rubber, and is connected at one end to the burette and at the other end to a small holder containing air and maintaining a pressure of 23-tenths, in order to prevent evaporation of the hydrocarbon and to ensure a steady downward flow against gas pressure.

407. The water is heated ready, and the flow of the hydrocarbon commences as the gas to be carburetted enters the apparatus. Ten observations are made for each cubic foot of gas, and the photometrical tests are made with the carburetted gas passing at a rate which would give a similar reading to that of the unenriched gas, the illuminating power thus varying with the rate. By adopting this means errors due to differences in the efficiency of the Argand burner are avoided and the burner used under the same conditions in both tests. (See also pars. 228 and 401.)

408. The following are figures obtained from an actual test of carburine with which 5 cubic feet of gas were enriched.

The carburine used had a gravity at 60° Fahr. of .674.

Barometer, 30.34

Thermometer, 70.0 Fahr. } Tabular number, .986.

Burette at start contained 81.1 septems.

Burette at finish contained 38.9 septems.

} Quantity of hydrocarbon used
= 42.2 septems.

The illuminating power tests were as under:—

Uncarburetted gas.

Height of flame, 3 inches.

Mean of readings on bar (uncorrected), 17.764 candles.

Mean rate of gas per hour (uncorrected), 5.648 cu. ft.

$\frac{17.764 \text{ candles} \times 5 \text{ cu. ft.}}{5.648 \times .986 \text{ (tab. No.)}} = 15.93 \text{ candles (corrected).}$

Carburetted gas.

Height of flame, $3\frac{1}{2}$ inches.

Mean readings on bar (uncorrected), 17.697 candles.

Mean rate of gas per hour (uncorrected), 4.616 cu. ft.

$$\frac{17.697 \times 5 \text{ cu. ft.}}{4.616 \times .986} = 19.44 \text{ candles (corrected).}$$

409. Now the difference in illuminating power is ($19.44 - 15.93$) 3.51 candles, the quantity of gas enriched is 5 cubic feet, the carburine used is 42.2 septems.

Therefore,

$$\frac{42.2 \text{ septems}}{3.51 \text{ candles}}$$

= 12.02 septems carburine enriched 5 cu. ft. 1 candle.

and

$$\frac{5 \text{ cu. ft. gas} \times 10,000 \text{ septems (1 gallon)}}{12.02 \text{ septems}}$$

= 4160 cu. ft. of gas enriched 1 candle by 1 gallon carburine;

therefore, 10,000 cubic feet require 2.4 gallons carburine, or, 1 ton (= 332.4 gallons) will enrich 1,382,784 cu. ft. of gas 1 candle. If the gas be enriched about $2\frac{1}{2}$ candles instead of $3\frac{1}{2}$ (as in above experiment) the quantity of carburine necessary to enrich 10,000 cu. ft. 1 candle will be reduced to 2 gallons.

410. *Test for Sulphur.*—It may sometimes be required to estimate the amount of sulphur in a sample of enriching oil, more particularly in benzol, in which case the oil can be burned in a suitable burner and the products collected in the same manner as the sulphur in gas test prescribed by the Gas Referees and described in Chapter IV. The arrangement of special burette, etc., given below (Fig. 56) affords a better method of burning the oil for this test, and is kindly placed at the writer's disposal by Mr. J. G. Taplay. As will

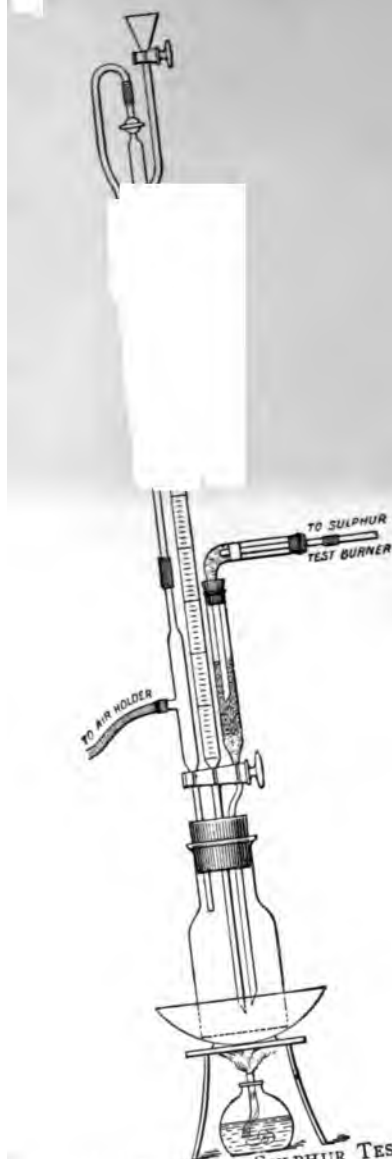


FIG 56.—APPARATUS FOR SULPHUR TEST IN OIL (

be seen from the illustration, the benzol or other material is placed in a 100-septem burette, and (under a pressure of 6 inches from an air-holder applied upon the surface of the benzol and upon the bottle where it is gasified) it is allowed to drop at about 60 drops a minute (for carburine about 35 drops per minute) upon the base of the bottle, which is heated by the hot-water bath. The air carries forward the vapour, which is burned in a slightly modified sulphur burner in the presence of sesquicarbonate of ammonia, condensed as usual in the sulphur test, and the products are collected. Strong ammonia may be poured through the condenser in small quantities as the experiment proceeds, otherwise the apparatus used (except that here illustrated) is exactly the same as that which is employed in the Referees' Sulphur Test.

411. The products, being collected, are treated with barium chloride, etc., and precipitated as BaSO_4 , as described

Chapter V. The precipitated BaSO_4 can be washed by decantation and transferred to a tared platinum crucible and the water evaporated slowly, the crucible and its contents being then subjected to a dull-red heat at first, gradually increasing to a bright-red heat. In this way the usual filter-paper is dispensed with. The amount of oil consumed being 100 septems, and 100 septems being the hundredth part of 1 gallon, and the amount of sulphur being ascertained in grains, it follows that this amount multiplied by 100 will give the grains of sulphur per gallon of oil tested.

Thus the amount BaSO_4 from 100 septems benzol was found to be 1.6 grains.

$$\begin{aligned} & 1.6 \times 100 \\ & = 160 \text{ grains from 10,000 septems (1 gall. benzol).} \\ & 160 + 138 = 298 \text{ grains sulphur per gallon benzol.} \end{aligned}$$

412. *Flash Point*.—The flash point of the light-enriching

oils will be very low, being many degrees below zero (freezing point). If a sample is placed in a beaker and surrounded by freezing mixture the temperature (as read by an alcohol thermometer) at which it will take fire will give an approximation of the flash point of the sample.

GAS-MAKING PETROLEUMS.

413. *Specific Gravity*.—The specific gravity of these oils can be obtained as described in paragraph 403.

414. *Enrichment Test*.—The enrichment value is best determined practically by treating a fair sample in the working



FIG. 57.—ABEL'S FLASH-POINT APPARATUS.

apparatus (large scale) and in the manner in which it will be used. A fair estimate of the value of an oil can be formed.

from a fractional distillation (described below), while a good oil should be reasonably free from sulphur, as can be determined by the use of the

415. *Sulphur test*, as described in paragraph 410 *et seq.*, modified to suit the sample of oil to be tested.

416. *The flash-point* should also be determined, and this may be done by an Abel's apparatus, which is illustrated in Fig. 57, and the instructions for the manipulation of which are quoted below. As gas-making petroleum has to be stored in bulk, the flash-point governs, to a certain extent, the method of its safe storage.

ABEL'S FLASH-POINT APPARATUS (Fig. 57).—The following instructions are extracted from the Petroleum Act, 1879 (42 and 43 Vic., c. 47), and are described as "The mode of testing Petroleum so as to ascertain the Temperature at which it will give off Inflammable Vapour":

"The test apparatus should be placed for use in a position where it is not exposed to currents of air or draughts.

"The heating vessel or water bath is filled by pouring water into the funnel until it begins to flow out at the spout of the vessel. The temperature of the water at the commencement of the test is to be 130° Fahrenheit, and this is attained in the first instance either by mixing hot or cold water in the bath, or in a vessel from which the bath is filled, until the thermometer, which is provided for testing the temperature of the water gives the proper indication: or by heating the water with the spirit lamp (which is attached to the stand of the apparatus) until the required temperature is indicated.

"If the water has been heated too highly, it is easily reduced to 130°, by pouring in cold water little by little (to replace a portion of the warm water) until the thermometer gives the proper reading.

"When a test has been completed, this water bath is again raised to 130°, by placing the lamp underneath, and the result is readily obtained while the petroleum cup is being emptied, cooled, and refilled with a fresh sample to be tested. The lamp is then turned on its swivel from

under the apparatus, and the next test is proceeded with.

" The test lamp is prepared for use by fitting it with a piece of flat plaited candlewick (the description of the wick known as Field's night-light candlewick has been found most suitable) and filling it up with colza or rape oil up to the lower edge of the opening of the spout or wick-tube.

" The lamp is trimmed so that when lighted it gives a flame of about 0.15 of an inch in diameter, and this size of flame is readily maintained by simple manipulation, from time to time, with a small wire trimmer.

" When gas is available, it may be conveniently used in place of the little oil lamp, and for this purpose a test flame arrangement for use with gas has been devised, which may be substituted for the lamp.

" The bath having been raised to the proper temperature, the oil to be tested is introduced into the petroleum cup, being poured in slowly until the level of the liquid just reaches the point of the gauge which is fixed in the cup. In warm weather the temperature of the room in which the samples to be tested have been kept should be observed in the first instance, and if it exceeds 65° , the samples to be tested should be cooled down (to about 60°) by immersing the bottles containing them in cold water, or by any other convenient method.

" The lid of the cup, with the slide closed, is then put on, and the cup is placed into the bath or heating vessel. The thermometer in the lid of the cup has been adjusted so as to have its bulb just immersed in the liquid, and its position is not under any circumstances to be altered.

" When the cup has been placed in the proper position, the scale of the thermometer faces the operator.

" The test lamp is then placed in position upon the lid of the cup, the lead line or pendulum which has been fixed in a convenient position in front of the operator is set in motion, and the rise of the thermometer in the petroleum cup is watched.

" When the temperature has reached about 66° , the operation of testing is to be commenced, the test flame being applied once for every rise of one degree in the following manner:

" The slide is slowly drawn open while the pendulum performs *three* oscillations, and is closed during the *fourth* oscillation.

NOTE. If it is desired to employ the test apparatus to determine the flashing points of oils of *very* low volatility, the mode of proceeding is to be modified as follows:

"The air chamber which surrounds the cup is filled with *cold* water to a depth of one and a half inches, and the heating vessel or water bath is filled as usual, but also with cold water. The lamp is then placed under the apparatus and kept there during the entire operation. If a very heavy oil is being dealt with, the operation may be commenced with water previously heated to 120°, instead of with cold water."

417. The distillation of a sample of oil is effected in the usual manner, a measured and weighed sample being placed in a weighed flask which is connected to a suitable fractionator, and thence to a condenser. The size and description of flask, etc., depend upon the nature of the sample to be examined; 100 cubic centimetres is a suitable quantity, if a "light oil" is being examined, while a suitable quantity of a solar distillate would be one litre, 1000 cubic centimetres. The temperatures between which each fraction is distilled over are recorded, as is also the volume and the weight, together with the nature of the fraction (colour, etc.). The distillates are collected in quantities of about 10 per cent. of the original sample, and at approximately the same temperature. The residue, which is weighed and its weight and nature noted, should not be more than about 1 per cent. of the original sample. The amount of water deposited (which should be very small) is also noted. The heat is applied gradually, and adjusted so that the distillates *drip* from the condenser into the collecting vessel. A test with acetate of lead papers can be made with each fraction for the presence of sulphuretted hydrogen. Cork stoppers should be used and not india-rubber ones, as the latter will generate H_2S . The sum of the fractions plus residue should be within 1 per cent. of the original sample, the difference being loss on distillation.

418. The following oils are chiefly used for carburetting

water gas, the data being kindly supplied by Mr. W. T. Leonard of Messrs. Carless, Capel & Leonard:

- (1) *Russian Solar distillate*. Specific gravity, .870 to .890. Flashing point about 150° Fahr., Abel's Close Test.
- (2) *American Gas Oil*. Specific gravity, .845 to .865. Flashing point between 80° and 120° Fahr.
- (3) *Roumanian Solar distillate*. Specific gravity, about .865. Flashing point about 100° Fahr.
- (4) *Borneo Solar distillate*. Specific gravity, about .890. Flashing point about 150° to 200° Fahr.

These oils should be composed of clean runnings from stills, and should have no residuum oils in admixture. A distillation should show them to be practically free from water, while there should be no great indication of sulphur until toward the end of the distillation, while the solid residue on distillation should usually be about 1 per cent., and never exceed 2 per cent.

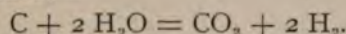
CARBURETTED WATER GAS.

418a. Although it is beyond the scope of this work to enter into questions of gas manufacture, the writer feels justified in including the following notes upon Carburetted Water Gas, because, apart from the various considerations which lead to the adoption of this method, such as want of space or labour, surplus supplies of coke or low price obtainable for same, necessity of an easy and economical method of increasing the bulk of a gas works' output and so on; carburetted water gas is often considered chiefly as a convenient method of enrichment. It may, therefore, be looked upon as an "enrichment material," and the following explanation of the chemical composition of the gas and tests required for same will not be out of place here. The water gas made in this country is manufactured in what is known

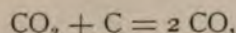
s the Lowe plant, and the form chiefly used is that introduced here by Messrs. Humphreys and Glasgow, in which the process of gas making is intermittent, consisting of alternate "blows" and "runs."

The plant consists of:

1. *The generator* in which coke or other suitable fuel is treated, subjected to a blast of air, and then decomposed by a supply of superheated steam, the product being uncarburetted, or "blue" water gas, are the following equations theoretically show. Carbon has an affinity for oxygen (O), as is well known. The heated fuel consists theoretically of carbon (C), the steam of H_2O . At certain temperatures, up to about 1100° Fahr., the following reaction takes place:—



Above this temperature and up to about 1850° Fahr. the carbon dioxide (CO_2) takes up another atom of carbon (C), making a product according to the following equations:—



and $2 CO + 2 H_2 =$ theoretical uncarburetted water gas.

As a matter of fact, this ideal state—the production of pure water gas, odourless, non-luminous, and of a high-flame heat—is never quite reached, some CO_2 still being left; but with proper working of heats and admixture of steam, not more than 3 per cent. of CO_2 should remain in the uncarburetted water gas.

So much for the generator.

2. *The carburetter* is a vessel (brought to a suitable heat by the absorption of part of the sensible heat of the blast, which is practically producer gas) in which the blue water gas is brought into intermixture with suitable oil, which is led (being previously heated by economical absorption from the finished gas) into the carburetter, and there being sprayed, becomes volatilised, and forms the mixture with the blue water gas known as carburetted water gas. This product is then led into

3. *The superheater*, which is a vessel also brought to a high heat by the hot blast, and in which the permanent gasification of the oil and "fixing" of the gas is completed.

The carburetted water gas is then washed, condensed and passed either to a relief holder, where it can be mixed in pre-determined proportions with the coal gas, or taken directly into the coal gas supply, being in either case purified in the same manner as coal gas.

418b. *Testing Carburetted Water Gas.*—The efficient management of a plant is a matter of experience, but the following tests, which are practically required in coal-gas testing, are particularly useful in this connection:

CO₂ Present in the Generator.—It has already been stated that there should be but a small amount of carbon dioxide in the blue water gas. The extent of its presence (the quantity will vary during the "run") can be ascertained by drawing gas off in burettes, during intervals of the "run," and subsequently testing same for presence of CO₂ by any of the more expeditious methods described in the chapter on gas analysis.

CO₂ present in the carburetted gas should not exceed 3 per cent. Its volume can be measured by any convenient method described in chapter 8, such as Sheard's test, in which the gas is led into a solution of barium hydrate, having a known equivalence to a decinormal solution of HCl, 1 volume of which = 0.0022 gramme CO₂, and with which solution the barium hydrate is afterward titrated, and thus the amount neutralised by CO₂ ascertained.

Other Impurities Present in the Carburetted Water Gas.—The gas will be practically free from NH₃ and sulphur compounds other than H₂S, and it will, therefore, only require purification for this latter and CO₂, unless the amount of CO₂ is deemed to be so small as to have no deteriorative effect upon the illuminating power of the mixed coal and water gas.

Photometrical Test.—It may be desired (and in many works it is the custom) to test the make of C. W. G. for illuminating power in the same way that coal gas is by the Jet Photometer. A Jet Photometer, however, will not answer for carburetted water gas, and the method adopted, therefore, is the use as a continuous test of a rapid reading Photometer, such as is described at the end of chapter 1, and which can be handled by a workman who would be capable of using a Jet Photometer.

attention is again directed to the importance of using a suitable burner, which will develop (as does the 24-hole Arnd for 16-candle gas) the highest illuminating power of the gas being tested. (See pars. 228 and 401.) The carbon monoxide in water gas may be estimated by cuprous-chloride sorption in the same way as is the CO in coal gas. (See chapter on Gas Analysis.) The following are figures of an analysis of blue and carburetted water gas, the latter being made from American oil, and having an illuminating power of 31 candles and a specific gravity of 0.6355. The figures are taken from a paper read before the American Gas Light Association in October, 1890, by Mr. A. G. Glasgow :

	Uncarburetted water gas. Per cent. by vol.	Carburetted water gas. Percent. by vol.
CO ₂	3.5	
CO ₂ + H ₂ S		3.8
C _n H _{2n} (heavy hydrocarbon)		14.6
CO	43.4	28.0
CH ₄		17.0
H	51.8	35.6
N	1.3	1.0
	100.0	100.0

LIME.

419. Lime used in gas works is known as quick, or caustic, lime, the formula for which, when pure, is CaO, and which is obtained from the burning of limestone, containing, with impurities, calcium carbonate (CaCO₃). This when burnt is decomposed into CaO and CO₂, which latter escapes. It is the CaO which is used at gas works, but which is slaked or hydrated before being put into the purifiers, the absorption, by the CaO, of water forming it into slaked lime or hydrate of lime (CaO, H₂O). The following makes this clear:

- (a) $\text{CaCO}_3 + \text{impurities} = \text{limestone.}$
- (b) Burning $\text{CaCO}_3 = \text{CO}_2$ (which escapes) + CaO ,
quick or caustic lime.
- (c) Slaking (*i. e.*) $\text{CaO} + \text{H}_2\text{O} = \text{CaO}, \text{H}_2\text{O}$, slaked or
hydrate of lime.

420. Since it is the $\text{CaO}, \text{H}_2\text{O}$ which is useful for purifying, it is obvious that the more pure CaO there is in a sample of quicklime, and the greater its affinity for water, the greater will be the amount of slaked lime or valuable purifying material. Quicklime ought, therefore, to be practically pure and consist (as it theoretically should) of CaO only, because if there is any CaCO_3 , for instance, present, due to inefficient burning of the limestone, there will not be so much available CaO to combine with the water on slaking as above. It is, therefore, useful to test lime

- (1) *For the percentage of CaO ascertained from amount of water it will take up in slaking.*
- (2) *For the amount of carbonates present.*

421. *The amount of CaO present in quicklime is based upon an observation of the amount of water taken to combine with a given amount of the quicklime, and so ascertaining by inference the amount of CaO .* In order to carry out the test it is necessary to know the proper condition of slaked lime. It is probably superfluous to state that the slaking forms a light powder, the addition to which of weak HCl causes only a slight effervescence. This fact in itself serves as a guide to the thoroughness of the burning process, because great effervescence would mean a large amount of CO_2 present, and slight effervescence (as there should be) the converse. Weigh a small sample of quicklime (CaO) into a basin, add water to thoroughly slake. Dry in an air oven to free from uncombined moisture, at a temperature of about 250° Fahr., and when dry, weigh. The increase

of weight is due to the amount of water absorbed, from a knowledge of which the percentage of pure quicklime (CaO) present can be ascertained. The combining weights of water and CaO are, respectively, 18 and 56, therefore the increase of weight (*i. e.*, amount of water absorbed), if divided by 18 and multiplied by 56, will give the amount of pure CaO . The increase, and therefore the amount, of CaO can be expressed in percentage; for comparative tests of different samples comparable conditions must be observed, such as equal moisture of sample before being slaked, equal drying at the same temperatures.

422. *The amount of carbonates present in slaked lime* can be found in several ways. Two methods are described below, the first being used by Mr. T. S. Lacey. The apparatus is an arrangement of Scheibler's Calcimeter, and is shown in Fig. 58. *A* is a CO_2 generating bottle, *B* a test tube with hole and lip in side to hold HCl , *C* a Woulffe's bottle with a skin bladder inside it, *D* a 100 c.c. burette, *E* companion tube, and *F* pressure bottle.

Half a gramme of dried slaked lime (a portion of the sample tested as in par. 421 will do) is put into the bottle, *A*, and 10 c.c. of dilute HCl (1 part acid to 2 parts water) is placed in the tube, *B*, which has a hole in the side, as shown. The apparatus is connected up, and then the bottle, *A*, is tilted to one side and the HCl runs out of the tube through the hole and on to the lime, causing an evolution of CO_2 , if carbonates are present.

Any CO_2 that is generated fills the thin skin bladder in bottle, *C*, which as it expands displaces the air surrounding it. This displaced air is measured in the burette, *D*, at atmospheric pressure (obtained by the use of the companion tube, *E*, and pressure bottle, *F*). About 5 per cent. is added to the burette reading, because the dilute HCl used dissolves a little of the CO_2 . The atmos-

pheric temperature near the burette and a reading of barometer should be taken and from these the tabular number is found, which, used as a multiplier, corrects the volume

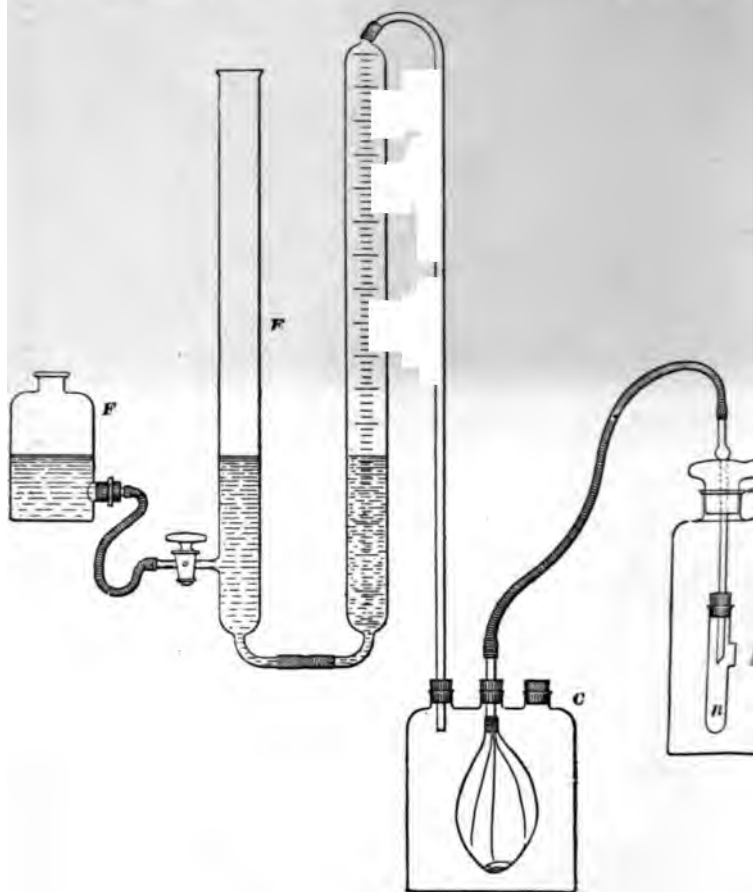


FIG. 58.—CALCIMETER AND APPARATUS.

of air measured in the burette. Properly speaking, the correction should be made for *dry gas*, and the tables (D in Appendix) are for moist gas; but the error is not a large

one, and, since the test itself is not an "exact" one, can be neglected. It is obvious that the amount of air measured in the burette is the amount displaced by the CO_2 , and therefore represents the volume of the latter which has been generated. This volume, when corrected, can be converted into percentage of carbonate (as CaCO_3) in the sample, as the following example shows.

423. *Example of test of slaked lime made with calcimeter:*

Burette reading	7.00 c. c.	Barometer, 30.1
Add 5 per cent.	0.35 c. c.	Thermometer, 68° Fahr.
		Tabular No. .983.
Total.	7.35	
Multiply by Tab. No.	.983	
	7.22505 c. c.	from $\frac{1}{2}$ gramme
		slaked lime.
Multiply by.	200	
	1445.01	from 100 grammes slaked
		lime.

At standard temperature and pressure 1 gramme of CO_2 has a volume of about 538 c. c. $\therefore$ the weight of CO_2 found is

$$\frac{1445.01}{538} = 2.685 \text{ grammes.}$$

Calcium carbonate is made up of 56 parts CaO and 44 parts of CO_2 ; total (or molecular weight) = 100 $\therefore$ the amount of CaCO_3 equivalent to 2.685 grammes of CO_2 will be

$$\frac{2.685 \times 100}{44}$$

= 6.1 grammes of carbonate of lime, which represents the percentage in the slaked sample.

424. *The second method of ascertaining the carbonates present* also affords an alternative means of estimating the amount of CaO in the quicklime, as follows:

Take a portion of the hydrate obtained (from test as par. 421), weigh, and note.

Dissolve it in a measured quantity of normal HCl—which should be in excess. Then titrate in burettes graduated in cubic centimetres, with normal soda solution, using a suitable indicator, say methyl orange. Alkalies change the colour of this indicator to yellow and this changes to red on the addition of an acid. In this test the colour change takes place from red to yellow.

The number of c.c. of HCl used less the number of c.c. of soda solution required to neutralise the acid solution will give the number of c.c. of HCl which have been neutralised by the CaO, and from this the amount of pure CaO can be calculated and expressed in terms of slaked lime or quicklime.

425. There should not be much carbonate of lime present if the CO_2 has been expelled in the burning of the limestone. Its presence will be seen by effervescence when the normal HCl is added as above, and its quantity can be determined by treating a weighed sample of the slaked lime with acid and evolving CO_2 and absorbing same in soda-lime tubes, the amount of CO_2 being calculated from increase of weight in the soda-lime tube. From this figure the amount of CaCO_3 is easily calculated.

426.—*Silica and Other Impurities in Lime.*—The silica (and possibly small quantities of clay, and anything, in fact, which will be useless for the absorption of CO_2 in the lime purifiers) can be estimated in the same sample used in the calcimeter test by completely dissolving all the lime with the HCl, transferring to an evaporating dish and evaporating to dryness. More HCl is added to the residue, and then distilled water is added and the whole passed onto a filter-paper. The precipitate is dried, ignited and weighed as silica and clay.

Note.—It will be found advisable to test lime after it is slaked, because the samples of hydrated lime can always be

dried at the same temperature (see par. 421), and thus comparable tests upon different samples obtained.

427. It is often desirable to revivify spent lime, particularly when the cost of new lime is high. This revivifying can be well and economically carried out by G. R. Hislop's patent process, in which the lime is burnt in a specially designed apparatus. The process is especially suitable where the spent lime consists principally of carbonate, having been used in a purification system where the sulphur has been removed by oxide of iron. The patentee claims that an economy is effected by means of the apparatus, and describes means of not only utilising it for recovery of carbonate of lime, but also of sulphate of lime. The process has been in successful use for some years. The tests recommended by the patentee to be carried out upon the recovered or revivified lime are as follows:

428. *CaO in Recovered Lime.*—Ammonia and ammonium oxalate are added to a sample, which precipitate the lime as oxalate of lime. The precipitate is filtered, washed, dried and ignited. During ignition the oxalate of lime is converted into carbonate, and as the carbonate of lime when strongly heated loses part of its carbonic acid, it requires to be drenched on cooling with carbonate of ammonium, then brought for two or three seconds to about 600° Fahr. to expel excess of carbonate of ammonium. The precipitate thus heated is then weighed as CaO_3 , from which the percentage of CaO can be calculated.

429. *H₂SO₄ in Recovered Lime.*—25 grains of the original sample are dissolved in 4 ounces of water and 1 ounce of hydrochloric acid, filtered and diluted to 12 ounces with water. Then add barium chloride in excess, with the usual precautions, as in the Referees' Sulphur Test (Chapter IV). The precipitate is weighed as barium sulphate, and from this the amount of sulphuric acid is ascertained.

430. *Total Sulphur in Recovered Lime.*—25 grains of the original sample are dissolved in $\frac{1}{2}$ ounce of HCl and HNO_3 , and then evaporated nearly to dryness. Then $\frac{1}{2}$ ounce HCl is added and evaporated as before, the residue being taken up with a solution of HCl (1 part acid to 8 of water), filtered, treated with barium chloride, and sulphur estimated as in paragraph 429.

431. *CO_2 in recovered lime* may be estimated by treating a sample of the recovered lime with acid, thus evolving CO_2 . The CO_2 is absorbed by soda lime in Geisler's apparatus, and its value calculated from the increase of weight due to the absorption. (See par. 425.)

The above are only some of the methods in use for testing fresh and spent lime. For other methods the works of Butterfield and Hornby can be consulted.

Oxide of Iron.

432. The bog ore used in gas works is valuable according to the amount of ferric oxide and moisture it contains. The latter exists as "free" and "combined" moisture.

433. *To Ascertain Free Moisture in Ferric Oxide.*—Weigh out a sample previously pulverised and place in a watch glass, weight of which is known. Dry in water-oven for a few hours and weigh when constant. The difference is due to free moisture. The dried sample may be used in order to

434. *Test for Combined Moisture.*—Weigh a small portion of the dried oxide and place in a tared platinum crucible, igniting at a moderate heat. This will cause a further loss of weight, due to combined moisture and organic matter, and this loss in weight should be noted and added to the observed loss due to free moisture.

435. *Test for Ferric Oxide.*—The use of oxide of iron

as a purification material in gasworks is based, roughly speaking, upon the fact that the hydrated ferric oxide it contains absorbs sulphuretted hydrogen, converting the ferric oxide (Fe_2O_3) into ferric sulphide (Fe_2S_3), and also depositing free sulphur. On being exposed to the air the fouled ferric sulphide becomes oxidised, and this property enables the oxide of iron to be revived and used again until the sulphur liberated by each successive fouling forms such a mass of inert material as to prevent its further economical use. Dry oxide is not efficient, and, therefore, a determination of the amount of moisture present, as above, is necessary.

436. While the purification value can be ascertained by fouling small samples, as is subsequently described, it is desirable to ascertain the amount of ferric oxide which an ore contains. The test is based upon the following:

Potassium bichromate oxidises a ferrous salt, such as ferrous chloride, converting it to the ferric state, and from a solution of potassium bichromate of known equivalence the amount of iron contained in a ferrous salt can be ascertained by titration. If, therefore, we reduce a known weight of oxide (containing an unknown amount of ferric oxide) to a ferrous salt and then titrate with bichromate, we can from this ascertain the amount of ferric oxide in the sample of ore examined.

437. Weigh a small amount, say, 2 grammes, of bog oxide in which the free and combined moisture (433, 434) have been ascertained. Place same in a beaker and digest with fairly strong hydrochloric acid until the iron is extracted, which can be seen by the disappearance of the red colour from the bog oxide. The complete extraction of the iron can also be proved by testing a drop of the solution with a solution of potassium sulphocyanide, when there should be no decided red coloration. When the iron is extracted add distilled water and filter, making up the filtrate and wash-

ings to a known quantity. The iron present as a ferric salt has now to be reduced to a ferrous state. A known portion of the filtrate and washings is placed in a flask and two or three small pieces of zinc free from iron are added. The neck of the flask is stoppered with a stopper having one hole, into which is inserted a piece of glass tube with a short piece of thin rubber tube slipped over it. One end of this rubber tube is stoppered and a slit is made in the tube, thus forming a vent for the air, but preventing the contact of air with the solution, which should be treated without the presence of air. The solution is gently heated until all the excess of zinc is dissolved and the reduction is complete. The colour should change from yellow (ferric) to pale-green (ferrous). The complete reduction can be tested by placing a drop upon a white tile and adding a drop of fresh potassium ferricyanide, which will yield a *blue* colour if ferrous salts are present, and a brown tint if the reduction is not complete. Cool out of presence of the air and carefully titrate with a solution of standard bichromate of potash of $\frac{N}{10}$ strength.

using potassium ferricyanide as an indicator in the manner described above. When the oxidation or conversion of the ferrous to the ferric salt is complete a drop of the solution added to a drop of the ferricyanide of potassium should produce a *brown* colour. Suppose 2 grammes of bog oxide were weighed out in the first instance before drying, and the solution were made up to 500 c.c. before titration. Suppose half this amount was titrated, and required 40 c.c. of $\frac{N}{10}$ potassium bichromate to neutralise it, the following is the calculation:

$$\begin{aligned} 1 \text{ c.c. of } \frac{N}{10} \text{ potassium bichromate} &= 0.0056 \text{ grammes Fe} \\ \therefore 40 \text{ c.c.} \times .0056 \times 2 &= .448 \text{ gramme Fe.} \end{aligned}$$

The proportion of Fe_2 in Fe_2O_3 is $\frac{112}{160} = \frac{7}{10}$.

Therefore the amount of $\text{Fe}_2\text{O}_3 = 0.448$ grammes $\times \frac{10}{7} = 0.64$ grammes. But 2 grammes of moist oxide were taken.

$\therefore$ percentage is $2 : 100 :: 0.64 : X$. $X = 32$ per cent. Fe_2O_3 in the moist oxide.

438.—*Experimental Test of Oxide of Iron.*—It is very usual to ascertain experimentally the amount of sulphuretted hydrogen which a sample of oxide will absorb. To do this a small sample is taken, brought to what is judged to be the requisite degree of moisture, placed in a suitable vessel and fouled for about twelve hours. A part of the sample taken (in the condition of moisture in which it was placed in the fouling vessel) is kept, so that the percentage of moisture can be ascertained as above described. The oxide is revived by exposure to the air until all traces of the sulphide disappear; it is then dried and a sample kept, from which the amount of sulphur contained in it can be ascertained. (See test for sulphur in spent oxide, Chapter IX). The remainder is then moistened again, a sample kept for percentage of moisture test, and the fouling, etc., again repeated. This is done two or three times, and by these means the value of different oxides can be ascertained, and parallel tests upon the same oxide with different amounts of moisture also made. The tests for sulphur in spent oxide should always be made upon a dried sample, and the percentage of moisture being known, the result can be expressed in percentage on a wet or dry basis. For tests to be comparable they must all be made on the same basis. Alternatively a smaller sample can be fouled in a U tube, either by foul gas or sulphuretted hydrogen, and the sums of the difference in weight after each fouling will give an idea as to the amount of sulphur absorbed. The moisture of each sample is also ascertained as above.

439. *Sulphur in Spent Oxide.*—For this test see Chapter IX.

Weldon Mud.

440. *Weldon mud* is valuable as a purification material for the extraction of sulphuretted hydrogen according to the amount of manganese dioxide (MnO_2) it contains. *Weldon mud* is sold by percentage of MnO_2 contained in the moist material and, therefore, a test for moisture is necessary in addition to one for percentage of MnO_2 . An experimental fouling test can also be made, and a test for percentage of sulphur in the spent material.

441. *Moisture in Weldon mud* is estimated in a similar manner to the moisture test of oxide of iron. It should be carried out as soon as the sample is taken, the sample, on the basis of which the mud is purchased, being preserved in a stoppered bottle and used for this test, and also for the test for

442. *Manganese dioxide in Weldon mud*, which is carried out as follows:

Two solutions are required, viz., decinormal permanganate of potash solution (1. c.c. = 0.00435 grammes manganese dioxide) and a solution of ferrous sulphate. For the preparation and precautions in using the former, Sutton's "Volumetric Analysis" should be consulted. The ferrous sulphate solution is prepared by dissolving soft iron wire free from rust in sulphuric acid and making up to such a strength that on titration about 20 c.c. of the solution = about 70 c.c. of the $\frac{\text{N}}{10}$ permanganate of potash.

Now this latter has an oxidising effect upon the ferrous sulphate, as also has manganese dioxide, and therefore if a known amount of the ferrous sulphate (the equivalence of which to the permanganate is known) is added to a weighed quantity of the *Weldon mud* (which contains

manganese dioxide) a less amount of permanganate will afterward be required to neutralise the unoxidised ferrous sulphate, and from this the amount oxidised by MnO_2 , and consequently the amount of this latter is ascertained.

In using permanganate the complete reduction from the ferrous state (by oxidation) is known to have taken place when the violet tint imparted to the salt in solution just remains permanent.

Take a small known quantity of the ferrous sulphate solution, add a weighed quantity of Weldon mud, heat gently until this latter is dissolved, and when cold titrate

with the $\frac{N}{10}$ permanganate of potash.

Suppose. 20 c.c. of the ferrous solution = 70 c.c. permanganate and 0.4 gramme Weldon mud were added to 20 c.c. of the ferrous solution.

and then only 50 c.c. of permanganate were required to oxidise the ferrous solution—

It follows that there was present of MnO_2 the equivalent to $(70-50) = 20$ c.c. of permanganate of potash.

Assuming this was exactly decinormal—

then 1 c.c. = 0.00435 gramme MnO_2 ,

or $20 \text{ c.c.} \times 0.00435 = 0.087$ gramme MnO_2 .

But 0.4 gramme Weldon mud was taken, therefore the percentage of MnO_2 in the Weldon mud is as follows:

$0.4 : 100 :: 0.087 \text{ gramme} : X. \quad X = 21.75 \%$.

This percentage is on the dry basis, because the mud taken had been dried and the percentage of moisture calculated. From this the percentage on wet basis can easily be found.

443. *The experimental test of Weldon mud* for purifying value can be carried out as in paragraph 438. A portion of the spent mud should be dried and kept for the estimation of the

444. *Sulphur in spent Weldon mud*, which is carried out in a similar manner to the spent oxide sulphur estimation described in Chapter IX.

The Calorimetry of Enrichment Oils.

445. In pars. 238 to 258 the method of determining the calorific power of gas was described. From the description it will be clear that, given a modified form of burner to suit different liquid or gaseous fuels, the principles of the test hold good, and the method described can be applied to testing fuels other than ordinary gas. For instance, if it be desired to test producer gas, Dowson gas or blue water gas, a simple modification of the burner, namely, closing the air-holes and increasing the consumption, serves the purpose. If, however, it be desired to test the calorific power of an enriching oil, and of which complete combustion can be obtained by means of a wick or other lamp, it will be seen that the conditions are changed to a rather greater extent, because a gas meter no longer serves as a measure for the fuel, which must be weighed.

446. The modifications to the Simmance-Abady Calorimeter for this purpose consist of the provision of suitable lamps, of a separate stand to the Calorimeter, and a simple arrangement by which a balance (with a short stroke) can be slid below the lamp, which it is assumed has been lighted and placed under the Calorimeter, through which the water is running. The illustration, Fig. 37, and the following instructions for working make the process clear, it being assumed that the reader is familiar with the Calorimeter as described in paragraph 238 *et seq.*

447. Place stand with balance to the left, and Calorimeter to right, with outlet of products spout at back. Slide balance on runners to left till it is free of Calorimeter. Fill lamp with fuel, and after trimming carefully and lighting, allow it to burn until it is in perfect order. Turn on water to Calorimeter and let it run to waste till both thermometers at summit are equal; or, if a slight difference exists

permanently, make note of same and allow for it. Place lamp under Calorimeter with chimney or flame immediately under centre. Raise lamp into Calorimeter with right hand, and with the left slide balance underneath and let lamp rest. See that it is central. Allow it to burn till thermometers again become steady, in the meanwhile adjusting speed of water till outlet products thermometer is at atmospheric temperature. Weigh down outer pan of balance till lamp is only very slightly the heavier. It will rise as oil burns, and as indicator passes the level point switch water from waste to measuring flask and place small measure under products outlet, adding directly after a gramme weight (two if fuel burns very rapidly) to lamp pan, which, of course, again falls. Watch with hand on water outlet until balance indicator again shows level (owing to combustion of the gramme weight of fuel) and turn water to waste at the same moment. Weigh the water in measuring flask (if not graduated), correcting if necessary for temperature. You will thus have following data: Amount of fuel burnt (say, one gramme); amount of water collected while that fuel has been consumed (say, 2.25 litres); difference in thermometer readings (say, 5.2°C). Multiply litres by degrees—11.7 calories per gramme of fuel. A kilo-calorie is the amount of heat necessary to raise 1 litre (kilo) of water 1°C ., therefore, above simple calculation gives result.

448. The kilo-calorie is the calorie we mean when we say "calories per cubic foot," and in testing oils it will be desirable to express results in "*calories per gramme*." The above is the "gross" result, and in order to obtain net result, *i. e.*, to deduct the amount of heat which usually escapes during ordinary combustion as steam (see paragraph 247) it is necessary to multiply by 0.6 the amount of condensed products collected in c.c. (as explained in paragraph 247) for the combustion of each gramme of fuel, the gramme

being the unit in which the results are expressed. Thus, taking the above example of 11.7 calories per gramme gross, suppose condensed products collected from the combustion of 1 gramme of fuel = say, 3 c.c. Then $3 \text{ c.c.} \times 0.6 = 1.8 \text{ c.c.}$, which subtracted from 11.7 (gross result) = 9.9 *calories per gramme net*. To convert to lb. Fahrenheit degrees, *i. e.*, B. T. U., multiply by 3.97, which will give *B. T. U.'s per gramme of fuel*. To convert into B. T. U.'s or calories per gallon, take the number of grammes in a gallon (which will vary with the specific gravity of the fuel) and multiply result accordingly.

NOTE.—Water should be used from a tank in the room, so that temperature of air and water approximate. Watch water pressure gauge on Calorimeter carefully, and discard any test in which the water pressure or thermometers vary. Stand perfectly still during test; any abrupt movement causing an unsteady current of air will be reflected in the thermometers' indications.

It will be necessary to choose a suitable lamp according to the nature of the fuel to be tested. A set of such lamps is provided with the apparatus.

[NOTE.—Par. 449 is left blank to facilitate additions in a future edition.]

CHAPTER VIII.

PURITY TESTS FOR GAS IN VARIOUS STAGES OF MANUFACTURE.

450. It has been seen from Chapter V that what might be termed the official purity tests are:

(1) Referees' Sulphur and Ammonia Test for estimation of presence and quantity of these impurities.

(2) Referees' Sulphuretted Hydrogen Test for proving the *absence* of this impurity.

451. It is desirable, however, to have some method of quickly ascertaining sulphur and ammonia in purified gas, and this is not afforded by the Referees' Tests.

452. We also know that whatever the state of the finished or purified gas, it has contained various impurities during its course of manufacture, for the removal of which certain apparatus and methods are used, and the efficiency of these requires constant checking.

453. It is obvious, then, that tests other than those mentioned above are a necessity to a gas works, and, therefore, the present chapter is devoted to the consideration of the following, which are described in the order named:

Marshall's test for CO_2 and H_2S in crude gas.

Lewis T. Wright's test for CO_2 and H_2S in crude gas.

Gravimetric test for CO_2 in crude gas.

Volumetric test (J. T. Sheard's arrangement) for CO_2 in crude gas.

Volumetric test (Wanklyn bottle) for CO_2 in crude gas.

Folkard's test for H_2S in scrubbed gas.

Harcourt's test for CS_2 in purified gas (quick sulphur test).

Harcourt's test for CO_2 and H_2S in purified or unpurified gas.

Leicester Greville's test for H_2S in crude gas.

W. C. Young's test for CS_2 in purified gas (alternative sulphur test).

Wanklyn's test for H_2S in crude gas.

T. S. Lacey's test for NH_3 in purified gas (quick ammonia test).

T. S. Lacey's test for NH_3 in unpurified gas.

Colman & Smith's test for naphthalene in gas.

The test for carbon monoxide will be found in chapter X.

Tests for composition of furnace gas will be found in the same chapter.

454. *F. D. Marshall's Test for CO_2 and H_2S .*—Pass the gas at the rate of half to three-quarters of a cubic foot per hour through a small coke scrubber, thence through a series of U-tubes, as shown in Fig. 59, and finally through an experimental meter. In the tests for crude gas it is advisable to use a porcelain meter as made by Alexander Wright and Co., Ltd., as that material resists the action of the impure

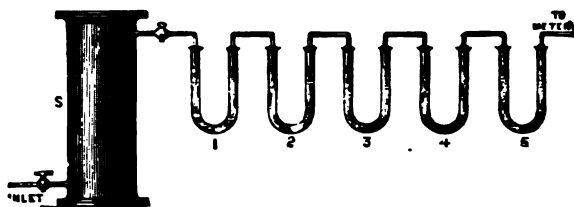


FIG. 59.—MARSHALL'S CRUDE GAS TEST FOR $\text{CO}_2 + \text{H}_2\text{S}$.

gas. The tubes may be about three inches long and half an inch internal diameter. The connections are made with reed tubes, as shown, and with accurately fitting india-rubber stoppers (or, preferably, good corks coated with paraffin wax). The tubes (Nos. 1 and 2) are filled with fragments of dry calcium chloride to absorb moisture, the next two with fragments of soda-lime, while the first limb and three-

fourths of the second limb of the last tube (No. 5) are charged with dry calcium chloride, and the remainder of the second limb charged with soda-lime. This tube guards the soda-lime tubes, and prevents the introduction of any moisture or CO_2 from the atmosphere. At the commencement of the experiment the two tubes 3 and 4, containing soda-lime, are accurately weighed, and also after five or ten cubic feet (or other measured volume) of gas have been passed through. *The increase in weight is due to the absorption of CO_2 and H_2S .*

455. *To Estimate H_2S Only.*—The gas is first passed through the "scrubber," *S*, as before, then through the arrangement shown in Fig. 60, and thence through the meter.

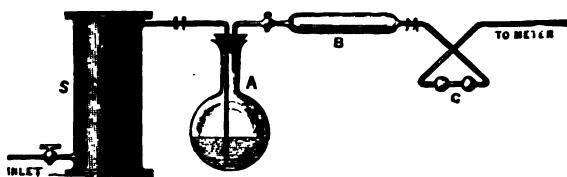


FIG. 60.—MARSHALL'S TEST FOR H_2S .

The flask, *A*, contains solution of caustic soda, *B* is a tube filled with glass beads, which are moistened with caustic soda solution, while *C* is a bulb tube to catch any liquid carried forward from *A* and *B*. After the passage of five or ten cubic feet (or other measured volume) of gas, wash the contents of the vessels out into a large beaker. Add solution of arsenite of soda, and then add sufficient hydrochloric acid to produce a strongly acid reaction, which may be ascertained by the decided reddening of a blue litmus paper dipped into the liquid. The sulphur of the sulphuretted hydrogen will be precipitated as trisulphide of arsenic, $\text{As}_2\text{S}_3 = 246$. Filter, well wash, and dry over a water-bath at 212° Fahr. Every 100 grains contains 39.02 grains of

sulphur, which when combined with hydrogen as H_2S in the proportion of 16 to 1, would give 41.46 grains for the weight of H_2S acted upon, or 6.25 per cent. very nearly, greater than the sulphur indicated. *Therefore, the weight of H_2S is found from the amount of Trisulphide of Arsenic precipitated.* (Sulphur $\times .3902 + 6.25\%$.)

456. *Example:*

Gas measured (after correction for temperature and atmospheric pressure)	= 10	cubic feet
Weight increased due to H_2S and CO_2	= 204.65	grains
Weight of trisulphide of arsenic..	= 98.04	grains
98.04 grains $\times .3902 + 6.25\%$ (as par. 455)	= 40.65	grains H_2S
		in 10 cubic feet
204.65 — 40.65	= 164	grains CO_2
		in 10 cubic feet

The following data will be found useful :

1 gramme = 15.43235 grains	
28,315.3 c.c. = 1 cubic foot	
The volume of 1 gramme CO_2 at 60° F. and 30" Bar.	= 538 cu. centimetres
The volume of 1 gramme H_2S at 60° F. and 30" Bar.	= 693.9 c.c.
1 gm. CO_2 = 0.019 cu. ft.	1 gr. CO_2 = 34.856 c.c.
1 gm. H_2S = 0.0245 cu. ft.	1 gr. H_2S = 44.965 c.c.
1 cu. ft. CO_2 = 812.348 gr.	1 gr. CO_2 = 0.001231 cu. ft.
1 cu. ft. H_2S = 629.7 gr.	1 gr. H_2S = 0.001588 cu. ft.
Now if 10 cu. ft. contained 40.65 grains H_2S ..	
100 feet	= 406.5
If 10 cu. ft. contained 164 grains CO_2 .. 100 feet	= 1640.0
∴ 406.5 $\times$ 0.001588 = 0.6455% H_2S	
∴ 1640 $\times$ 0.001231 = 2.01884% CO_2	

457. By the processes described above the gas has been measured after the removal of the H_2S and CO_2 , therefore the original volume is greater than that measured.

The percentage corrections are as under :

Gas measured	100	cu. ft.
H ₂ S ascertained per 100 feet..	0.6455	
CO ₂ " " " " ..	2.01884	
	102.66434	

So that the true percentages by volume of the impurities are :

$$\frac{0.6455 \times 100}{102.664} \text{ H}_2\text{S} = 0.63,$$

$$\text{and } \frac{2.01884 \times 100}{102.664} \text{ CO}_2 = 1.97.$$

458. *L. T. Wright's Test for H₂S and CO₂.*—This is a modification of C. R. Fresenius's method, and was described by Mr. Wright in a paper read before the Society of Chemical Industry in 1885. This is based on the fact that cupric phosphate absorbs H₂S, and its increase in weight gives the amount absorbed, while soda-lime absorbs CO₂ in the same manner. Three conditions are necessary—firstly, that the gas should be dry; secondly, that it should be free from ammonia; and, thirdly, that the cupric phosphate should have attained its limit of saturation of coal-gas before the test commences. The test is nothing more than a series of weighing tube experiments, but it requires to be carried out with care. Cupric phosphate is prepared by mixing 2 pounds of sodium phosphate (Na₂HPO₄), dissolved in a gallon of water, with 2½ pounds of crystals of copper sulphate dissolved in 1½ gallons of water. The mixture must be effected with vigorous stirring, the resultant bright blue precipitate being washed by decantation, and then dried at 100° Centigrade in a water-bath. The cupric phosphate will be sometimes powdery and sometimes in lumps; it can be crushed in a mortar. The soda-lime to be used should be moist. It can be exposed to a moist atmosphere for a few hours, and is

then ready for use. Take a six-inch U-tube with stoppers, which act as cocks and side inlet and outlet tube. Lightly plug the bend with cotton wool, charge one limb with cupric phosphate, the other with calcium chloride free from alkali. Pass three or four feet of clean (not foul) dry coal-gas slowly through, then weigh tube at intervals and (when increase of weight due to absorption of clean gas has stopped) note weight. Another similar tube is charged in same way, one limb with the moist soda-lime, the other with calcium chloride. Pass clean coal-gas sufficiently to expel air, weigh tube, and note weight. Take a drying cylinder and fill it with calcium chloride. Take a twelve-inch U-tube, fill it with pumice saturated with syrupy phosphoric acid. This is to remove ammonia; connect the tubes in following order:

459. First tube with syrupy phosphoric acid connected with service of foul gas to be tested. At the outlet connect drying cylinder, then connect this to the cupric phosphate tube (previously weighed), placing between the two a T-piece with the free arm provided with a cock for blowing off gas before starting experiment. Connect the soda-lime tube (previously weighed), and then on to a meter or an aspirator. Let the gas pass at about one-half cubic foot per hour, and let test run for, say, one hour. The duration depends on quantity of impurity; the absorbing tubes will take about twenty and fifteen grains of H_2S and CO_2 , respectively. When test is finished, note the quantity of gas passed. Now pass about one-half cubic foot of clean gas through the apparatus, letting it pass in train through a wash-bottle containing caustic potash, before the phosphate and soda-lime tubes. Now disconnect, weigh tubes, and calculate for weight and volume as in Marshall's test (pars 456, 457).

460. *Examples:*

For H_2S . Gas passed corrected for temperature and barometric pressure =

say 0.55 cubic feet.
Cupric phosphate tube after test = 1402.5 grains.
" " " before " = 1400

H_2S absorbed = 2.5 grains.

Divide 2.5 grains by .55 cubic foot = 4.54 grains per cubic foot. Now 1 grain H_2S = .0015878 cubic feet; hence, volume % is represented by following equation:

$$\frac{2.5 \times .0015878 \times 100}{.55} = .7217 \text{ cubic feet}$$

of H_2S per 100 cubic feet, or .7217 per cent. by volume.

For CO_2 . Volume of gas as before, 0.55 cubic feet.
Soda-lime tube after test 1808.6 grains.
" " before " 1800.1 "

CO_2 absorbed = 8.5 "

Divide 8.5 by .55 cubic foot = 15.45 grains per cubic foot. Now 1 grain CO_2 = 0.001231; hence, volume % is represented by following equation:

$$\frac{8.5 \times 0.001231 \times 100}{.55} = 1.9 \text{ cubic feet of } CO_2$$

per 100 cubic feet, or 1.9 per cent. by volume.

461. As in Marshall's test, the gas is measured after removal of H_2S and CO_2 , so the original volume of gas was greater than that measured. Taking the percentages by volume, then

Gas measured 100 cubic feet.
 H_2S 0.7217
 CO_2 1.9

102.6217

so that the true percentages of the impurities are

$$\frac{.7217 \times 100}{102.6217} \text{ of } \text{H}_2\text{S} = 0.70$$

$$\frac{1.89081 \times 100}{102.6217} \text{ of } \text{CO}_2 = 1.84$$

462. Carbon dioxide (CO_2) may be estimated in the crude gas by several other methods, among which may be mentioned the gravimetric and the volumetric methods. The former test is performed by absorbing the CO_2 (in a known volume of coal-gas) in a solution of barium hydrate; filtering off the precipitate, washing, igniting and weighing it as barium carbonate, and from the weight of barium carbonate ($\text{BaO} \cdot \text{CO}_2$) found calculating the amount of CO_2 , either to grains per 100 cubic feet of coal-gas or to volume per cent.

463. *Sheard's Test for CO_2 .*—The volumetric method is used by J. T. Sheard, a description of whose arrangement was published in the *Journal of Gas Lighting*. Butterfield, in his "Chemistry of Gas Manufacture," describes a similar method, which he also recommends for use with carburetted water gas. It is also used with the modified form of Wanklyn bottle, the manipulation of which is described below, as arranged by Mr. T. S. Lacey (Pimlico) for quick ammonia tests (pars. 499 *et sequitur*). All these volumetric methods consist in absorbing the CO_2 (in a known quantity of coal-gas) in an excess of a solution of barium hydrate of known strength, and then titrating the excess of barium hydrate with a standard solution of hydrochloric acid; the difference in the alkalinity of the barium hydrate solution before and after contact with the CO_2 will enable the operator to determine the amount of CO_2 in the gas under examination. As mentioned above, two solutions are required. A nearly saturated solution of barium hydrate is prepared; it should not be too concentrated, because, at low temperatures, it is

apt to deposit the hydrate. If a large quantity of this solution is to be kept it should be preserved in a covered vessel, from which the solution can be syphoned off, connecting in doing this the necessary air inlet tube with a soda-lime tube. This method will exclude the air from the solution, which latter would otherwise be continually depositing barium carbonate, and consequently the strength of the solution would vary from time to time. The other solution used in this test is a decinormal solution of hydrochloric acid (or $\frac{N}{10}$ HCl solution); such a solution will contain 3.637 grammes of HCl per litre. As the strongest hydrochloric acid is itself an aqueous solution of HCl, the standard solution required in this test may be prepared by weighing out 18.1 grammes of hydrochloric acid (free from chlorine gas or metallic chlorides), of a specific gravity of 1.10, and diluting to 1 litre with distilled water; or 126.7 grains of the acid may be diluted to 1 deci-gallon with distilled water. This will make a solution of approximately the correct strength; to prove this acid solution a small quantity of it may be treated with a solution of silver nitrate and the weight of the precipitated silver chloride observed. 25 cubic centimetres of the $\frac{N}{10}$ acid solution should yield 0.3576 gramme (nearly) of silver chloride. And 50 septems of the acid solution should yield 5.006 grains of silver chloride. The decinormal HCl can also be prepared by diluting normal solution (which can be obtained ready-made) with distilled water until 10 cubic centimetres, if titrated against normal sodium hydrate solution, will equal 1 cubic centimetre of the latter. Thus $\frac{N}{10}$ HCl is of such a strength that 1 c.c. = 0.0022 gramme of CO_2 .

463A. It is now required to know the strength of the barium hydrate solution by titration with the decinormal

hydrochloric acid solution. 25 cubic centimetres of the alkaline solution is run from a pipette into a small flask, and a few drops of a tincture of cochineal are added (some prefer the use of an alcoholic solution of phenolphthalein). Decinormal acid is run out of a burette, or an alkalimeter, of 100 c.c. capacity into the flask containing the barium hydrate until the purple coloration (indicating the free alkali) is changed to magenta in tint (indicating the neutral point); or, if phenolphthalein be used, until the pink coloration is discharged. This titration should be performed quickly, so as to avoid exposing the barium hydrate solution to the air for a longer time than is absolutely necessary. If properly prepared, 1 cubic centimetre of the $\frac{N}{10}$ hydrochloric acid solution is equivalent to 0.0022 gramme of carbon dioxide. Suppose the 25 c.c. of the barium hydrate solution required 40 c.c. of the $\frac{N}{10}$ HCl solution, for neutralisation, then the 25 c.c. of the alkaline solution will absorb 0.088 gramme of CO_2 ($40 \times 0.0022 = 0.088$).

464. In using Sheard's arrangement proceed as follows:

Connect together a small oxide purifier to extract H_2S with the two special absorption tubes requisite for this test. These consist of a flask with bulbs and a glass tube for use as a scrubber by filling with glass beads. (See Fig. 61.) The gas is drawn through these by means of an aspirator. Each of the flasks of the absorption tubes has placed into it a measured quantity of the standardised barium hydrate solution—into the first, say, 30 cubic centimetres, and into the second, say, 20 cubic centimetres—the inlet and outlet of the absorption tubes are stoppered with stoppers having one hole, and the gas is drawn through the oxide purifier, first into the flask, then from the tube into the flask of the

second absorption tube, and from the tube or scrubber portion of this into the aspirator. Make the connection from purifier while the gas is passing, letting some blow off first; then start the aspirator, and let 500 cubic centimetres of gas pass, disconnect the inlet of the first tube as the 500 cubic centimetres of water have passed from the aspirator, and draw through the apparatus about an equal amount of air. Then wash with distilled water through the scrubbers, collect the liquid, add a few drops of the phenolphthalein.

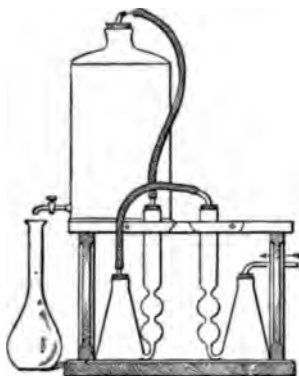


FIG. 61.—SHEARD'S CO₂ APPARATUS.

and titrate with the decinormal HCl. From the amount of free barium hydrate remaining the amount of CO₂ absorbed can be found. When the phenolphthalein is added to the barium hydrate solution a purple coloration takes place; when the neutralisation by the HCl is complete this colour disappears. Suppose the two tubes contained originally 30 and 20 cubic centimetres, respectively, and 500 cubic centimetres of gas were passed and 75 cubic centimetres of the $\frac{N}{10}$ HCl were required to neutralise the carbonated barium hydrate solution, of which 25 cubic cen-

timetres equals 40 cubic centimetres of the $\frac{N}{10}$ HCl solution (as in par. 463A). Then

The equivalent of the 50 c.c. barium hydrate	
used is	80 c.c. acid
There was required to neutralise liquid after	
test	75 c.c. acid

Equivalent of barium hydrate neutralised .. 5 c.c. acid
 To convert this into grains per cubic foot (where 500 c.c. of gas has been passed) multiply by the factor 1.922, thus:

$$5 \times 1.922 = 9.61 \text{ grains } CO_2 \text{ per cubic foot.}$$

To find percentage by volume (where 500 c.c. of gas has been passed) multiply by the factor .241; thus,

$$9.61 \times .241 = 2.31\% \text{ by volume } CO_2$$

The above factors are explained as follows:

$$1.922 = \frac{0.0022 \times 15.432 \times 28,315}{500}$$

where

1 c.c. of $\frac{N}{10}$ acid = 0.0022 gramme of CO_2

and 1 gramme = 15.432 grains

and 1 cubic foot = 28,315 c.c.

and 500 c.c. of gas was used.

Also:

$$0.241 = \frac{0.0022 \times 100}{0.914 \text{ gramme}}$$

where 500 c.c. of CO_2 = 0.914 gramme.

464A. Butterfield passes the gas from an oxide purifier through two two-necked Woulffe's bottles, thence through an aspirator. The supply is tapped after the purifier and the gas is burned, and this is advisable in all similar tests, as by that means a good circulation is assured. A thermometer might also be inserted in the aspirator (when same is used in place of a meter), so that temperature can be corrected. It should always be seen that the joints

are gas-tight, and care should be taken generally, as without precautions accurate results cannot be expected in Marshall's, Wright's, Sheard's, or any of these tests. The pressure of gas service should be controlled and kept low, generally not exceeding two inches, and if arranged on a pipe with several branches and cocks, the gas can always be burned from any of these points, and a good flow maintained. The service should be as short as possible, and whether iron or rubber pipe is used, it should be previously saturated with gas, and not new.

465. *CO₂ in Crude Gas by Modified Wanklyn Bottle.*—In order to determine the CO₂ in the coal-gas after the washers and scrubbers, and also in ascertaining the efficiency of the lime purifiers, the coal-gas should be passed first through a small experimental "oxide" purifier, and from thence into a dry $\frac{1}{16}$ th cubic foot gas bottle fitted with a hollow stopper, as described in paragraph 501. Suppose the coal-gas to be tested contained about 800 grains of CO₂ per 100 cubic feet, or equivalent to 0.985 per cent. by volume. From a pipette let fall 25 cubic centimetres of the barium hydrate solution into the hollow stopper of the gas-bottle and add a little recently boiled distilled water; fill the gas-bottle with the gas, insert the hollow stopper in the neck of the bottle and shake up the solution with the gas; now allow the liquid to drain back into the hollow stopper and transfer the contents to a flask; wash out the bottle and stopper with about 25 cubic centimetres of recently boiled distilled water, and add the washings to the contents of the flask. The whole is now titrated with $\frac{N}{10}$ hydrochloric acid, using phenolphthalein or cochineal as an indicator. Suppose that 16.5 cubic centimetres of the $\frac{N}{10}$ acid were run out of the burette, or the alkalimeter in order to neutralise the excess

of barium hydrate solution. Now, it has been previously ascertained that 25 cubic centimetres of the fresh barium hydrate solution is equivalent to 40 cubic centimetres of the $\frac{N}{10}$ HCl solution, so that if only 16.5 cubic centimetres of the $\frac{N}{10}$ acid is required for titration (after the barium hydrate solution has been in contact with the coal-gas) it is evident that an amount of barium hydrate solution equivalent to the difference between 40 cubic centimetres and 16.5 cubic centimetres $\frac{N}{10}$ acid (or 14.688 cubic centimetres of alkaline hydrate) has been used to combine with the CO_2 present in the sample of coal-gas, and the remainder of the alkaline hydrate (viz., 10.312 cubic centimetres) has been neutralised by titration with the $\frac{N}{10}$ acid, because this latter is the amount of the alkaline hydrate in excess. The difference between 40 cubic centimetres and 16.5 cubic centimetres being 23.5 cubic centimetres $\frac{N}{10}$ acid, and each cubic centimetre of the $\frac{N}{10}$ acid being equivalent to 0.0022 gramme of CO_2 , the amount of CO_2 in grammes per $\frac{1}{10}$ th cubic foot of coal-gas is obtained by multiplying the 23.5 cubic centimetres by 0.0022; this result is then multiplied by 1000 to obtain the amount of CO_2 in grammes per 100 cubic feet of gas. Then if this latter amount is multiplied by 15.43235, the result will be the amount of CO_2 in grains per 100 cubic feet of the gas.

Example:

$$\begin{aligned}
 &(23.5 \times 0.0022) \times 1000 \times 15.43235 \\
 &= 798 \text{ grains } \text{CO}_2 \text{ per 100 cubic feet of gas,} \\
 &\text{and } 798 \div 812.348 \text{ (the weight in grains of 1 cubic foot} \\
 &\quad \text{of } \text{CO}_2) \\
 &= 0.982 \text{ per cent by volume.}
 \end{aligned}$$

465A. The amount of CO_2 in grains, per 100 cubic feet of coal-gas, may be obtained quickly by multiplying the difference in the alkalinity of the alkaline solution, in terms of $\frac{N}{10}$ acid, by 34 (or more nearly 33.95117).

$$23.5 \text{ c.c. } \frac{N}{10} \text{ acid} \times 33.95117 = 798 \text{ grains of } \text{CO}_2.$$

$$23.5 \text{ c.c. } \frac{N}{10} \text{ acid} \times 34 = 799 \text{ grains of } \text{CO}_2.$$

If the amount of CO_2 , in volume per cent., be required, it may be quickly obtained by multiplying the difference in alkalinity (as above) by 0.0418.

$$23.5 \text{ c.c. } \frac{N}{10} \text{ acid} \times 0.0418 = 0.982 \text{ } \text{CO}_2 \text{ per cent. by volume.}$$

466. It may be noted that the solution of barium hydrate is of no standard strength; it is better to prepare the solution in quantity and standardise it with the $\frac{N}{10}$ acid each time a fresh lot is made. In using the $\frac{1}{10}$ th cubic foot gas-bottle the precipitated carbonate clings to the sides of the



FIG. 62.—FOLKARD'S TEST FOR H_2S .

vessel, and is with difficulty removed for the purpose of estimating the CO_2 by the gravimetric method; therefore

the latter method, as at first described, is preferable, as only the excess of barium hydrate solution is required. The presence of the barium carbonate in the liquid will not interfere with the titration, when using decinormal hydrochloric acid for the operation; the acid solution will not dissolve the carbonate until all the free barium hydrate has been neutralised. The barium carbonate, however, may be allowed to settle (in a closed vessel) and one-half of the clear liquid may be taken for titration, and the result obtained is then multiplied by 2 and the calculation proceeded with as described.

467. *Folkard's Test for H_2S in Scrubbed Gas.*—This is designed as a rapid test, and of it Mr. Folkard states that an intelligent workman can, with but little practice, take testings of a set of six or eight purifiers in about thirty minutes, and thus obtain a daily record of the work done by each purifier. The apparatus is shown in Fig 62, and serves to determine 0.1 to 2 per cent. of sulphuretted hydrogen in scrubbed gas. It consists of a glass tube about $\frac{3}{4}$ -inch in diameter, permanently closed at one end, and with a capacity of 60 septems. This serves to hold the gas to be tested, and is filled by displacement by holding it (open end downwards) over a lamp-cock, furnished with a piece of india-rubber tube 3 or 4 inches long, to conduct the gas to the top end of the "gas tube." The smaller or solution tube is divided into 20 septems, and provided with a sliding stopper which can be adjusted for varying quantities of iodine solution from 1 to 20 septems—*each septem of solution being equal to 0.1 per cent. of the sulphuretted hydrogen in the sample of gas tested.*

The iodine solution sent out is a "Stock Solution," and should be diluted with water in the proportion of one part of iodine solution to five parts of water.

468. *To Make a Test Proceed as Follows:*—Place the

test-glass, open end downward, over the lamp-cock, and while it is filling adjust the sliding top in the "solution tube" to the number of septems relative to the percentage of sulphuretted hydrogen you suspect to be present, and fill to the top with solution; and while holding the test-glass in one hand over the cock insert the solution tube up to the stopper, and, holding the stopper firmly in place, briskly shake up the solution with the sample of gas thus enclosed. Provided enough iodine solution to have been taken, all the sulphuretted hydrogen should be destroyed. To ascertain this a small slip of acetate of lead paper is inserted into the tube by partially withdrawing the stopper. If the paper be blackened a second adjustment of this is made and more iodine solution is put into the solution tube, a fresh sample of gas taken and the test repeated. If the lead paper is not discoloured, less iodine solution is taken and a fresh trial made, and so on until a sufficiently close approximation is obtained. As previously explained, the percentage of sulphuretted hydrogen is obtained by the amount of iodine solution required. Say, for example, that first you take 10 septems of iodine solution and find, upon applying, the lead paper is not discoloured; and, second, having taken 9 septems of solution, there is a very slight discoloration of the paper, then you know that there is about .9 per cent. of sulphuretted hydrogen.

469. *Harcourt's Colour Test* for CS_2 , or total sulphur in Purified gas.—This is a well-known test, and perhaps affords the only widely-used rapid means of ascertaining the amount of sulphur impurities in coal-gas. The arrangement is shown in Fig. 63, the chimney of the burner being shown in dotted lines. The bulb, which is filled with platinised pumice, is to be so adjusted that it may be about an inch above the burner and in the middle of the chimney. To use the apparatus, turn on first the upper stopcock, sending gas

through the bulb at the rate of about half a cubic foot an hour, as may be judged by lighting the gas for a moment at the end of the horizontal arm, when a flame about an inch in length should be produced. Light the burner and turn down the flame till it forms a *blue, non-luminous ring*, then place the small clay-pieces upon the top of the chimney round the neck of the bulb. A testing may be made five

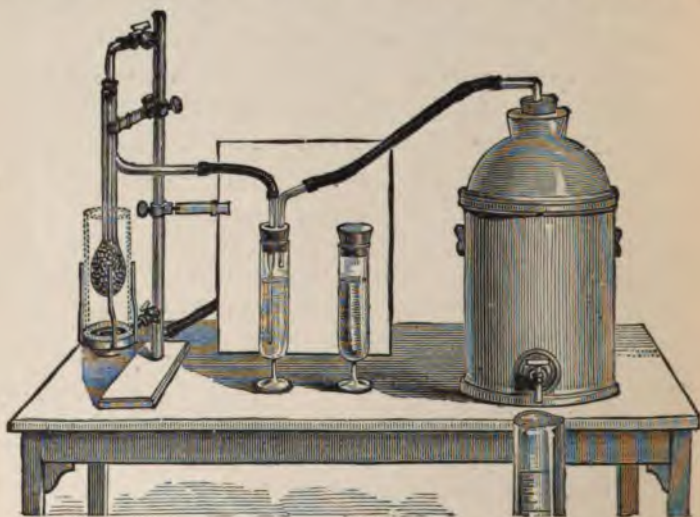


FIG. 63.—HARCOURT'S COLOR TEST.

minutes after the burner is lit, except when the apparatus is first used, when the gas should be allowed to flow through the bulb for a quarter of an hour or a little longer, and any number of testings may be made one after another as long as the heat is continued.

470. *The Mode of Testing is as Follows.*—Place the piece of opal glass in the back of the comparison box. (The figure shows a sheet of cardboard, but a small box which takes the Standard Colour and the Test Tube, and which has an opal back, is now used.) Put the Standard Colour Tube

in one of the holes in the box. Now dilute some of the lead syrup solution with about twenty times its volume of distilled water, and fill the test-glass up to the mark with the solution thus prepared. Insert the caoutchouc plug with capillary tube (which should descend very nearly to the bottom of the glass, but must not press upon the bottom, or it will probably be broken) and elbow tube, and connect, as shown in the figure, with the bulb and aspirator, placing the two glasses side by side in the comparison box.

471. There are two colour standards, one for daylight and the other for gaslight, which are sent out in sealed glasses. When using the gaslight standard the gaslight employed should be a flat-flame or argand emitting yellow rays; the incandescent (white mantle) will not do. The glass containing the Standard Solution should always be shaken before commencing a test.

472. *The aspirator must be quite full of water at starting, and the measuring cylinder empty.* Turn the tap of the aspirator gradually; a stream of bubbles will rise through the solution of lead. Turn off the tap for a minute, and observe the liquid at the bottom of the capillary tube. If it gradually rises, the india-rubber connections are not air-tight and must be made so before proceeding. *Avoid pressing the plugs into the glass or the aspirator while they are connected,* which would drive up the lead solution into the inlet tube. When the connections are air-tight, let the water run into the measuring cylinder in a *slender stream* until the lead solution has become as dark as the standard. As the ascending bubbles interfere somewhat with the observation of the tint, it is best to turn off the tap when the colour seems almost deep enough; compare the two; turn on the tap, if necessary, for a few moments, then compare again, and so on till the colour of the two liquids is the same.

473. *The volume of water which the measuring cylinder*

now contains is equal to the volume of gas which has passed through the lead solution.

474. This volume of gas contained a quantity of sulphur as carbon bisulphide which, as lead sulphide, has coloured the liquid in the test-glass up to the standard tint. The standard has been made such, that to impart this tint to a volume of liquid 0.0187 grain of lead sulphide must be present, containing 0.0025 grain of sulphur. Hence, suppose the measuring cylinder, each division of which corresponds to $\frac{1}{2000}$ cubic foot, to have been filled to the 30th division. $\frac{30}{2000}$ cubic foot of gas contained 0.0025 grain of sulphur. From this ratio the number of grains of sulphur existing in the carbon bisulphide (CS_2) in 100 cubic feet of the sample tested can easily be calculated.

475. TABLE I.— $S = \frac{500}{V}$

V.	S.	V.	S.	V.	S.	V.
10	50.0	33	15.1	56	8.9	79
11	45.4	34	14.7	57	8.8	80
12	41.7	35	14.3	58	8.6	81
13	38.5	36	13.9	59	8.5	82
14	35.7	37	13.5	60	8.3	83
15	33.3	38	13.2	61	8.2	84
16	31.3	39	12.8	62	8.1	85
17	29.4	40	12.5	63	7.9	86
18	27.8	41	12.2	64	7.8	87
19	26.3	42	11.9	65	7.7	88
20	25.0	43	11.6	66	7.6	89
21	23.8	44	11.4	67	7.5	90
22	22.7	45	11.1	68	7.4	91
23	21.7	46	10.9	69	7.2	92
24	20.8	47	10.6	70	7.1	93
25	20.0	48	10.4	71	7.0	94
26	19.2	49	10.2	72	6.9	95
27	18.5	50	10.0	73	6.9	96
28	17.9	51	9.8	74	6.8	97
29	17.2	52	9.6	75	6.7	98
30	16.7	53	9.4	76	6.6	99
31	16.1	54	9.2	77	6.5	100
32	15.6	55	9.1	78	6.4	150

The above table gives the relation between (V) the divisions of the measuring cylinder filled with water and (S) the grains of sulphur *existing as bisulphide* in 100 cubic feet of gas. Since gas contains, besides carbon bisulphide, some other sulphur compounds which *are not transformed into sulphuretted hydrogen* by the action of heat, and which contain sulphur amounting ordinarily to 7 or 8 grains in 100 cubic feet, this quantity *must be added* to that found by the Test if it is wished to know approximately the *total amount of sulphur* in the gas. Where it is desired to test unpurified gas for CS_2 , the H_2S must first be removed by an oxide purifier.

476. For the next testing the test-glass is to be disconnected and recharged. The water in the measuring cylinder is poured back into the aspirator. The colour of the standard is unaffected by exposure to light, but deepens if the liquid is warmed, returning to its original shade as the liquid cools. If, therefore, the glass containing the standard has been in a warm place, it must be let cool before testing. The liquid which has been used becomes colourless after being exposed to the light for a few hours, and may thus be used over and over again for twenty times or more *if it is not allowed to absorb carbonic acid from the air*. The best mode of working is to have two well-corked flasks, into one of which the coloured liquid is emptied, while the glass is recharged from the other. The platinised pumice serves when heated to break up the carbon bisulphide present, producing an equivalent quantity of sulphuretted hydrogen, upon the absorption of which by the lead solution the test is based. After a hundred or more testings have been made its action becomes less perfect, owing to a slight deposit of carbon. If, in testing, the burner beneath the bulb is used with a luminous instead of a blue ring of flame, this deterioration happens sooner. The platinised pumice can be re-

stored to its original state without being removed from the bulb, by drawing air through the bulb by means of the aspirator, while the burner flame is rather higher than when a testing is being made. The pumice is shown to have been burnt clean when, on drawing the air through a clear solution of baryta water (as in making a test for carbonic acid in coal-gas) no turbidity of the fluid takes place.

477. *Estimating H_2S and CO_2 by the Harcourt Apparatus.*—The sulphuretted hydrogen in gas at any stage of manufacture may also be ascertained by this apparatus. The gas is led in this case directly into the test-glass, which is charged with lead solution for sulphuretted hydrogen, and with a saturated solution of barium hydrate (baryta water) for carbonic acid. The burner is dispensed with. When the gas contains more than 50 grains of sulphur as sulphuretted hydrogen in 100 cubic feet, a smaller cylinder, containing $\frac{1}{10}$ cubic foot, is used to measure the volume of liquid run from the aspirator. The divisions on the smaller cylinder are tenths of the corresponding divisions on the larger cylinder; therefore when it is used the numbers under S in Table I. must be read as whole numbers by omitting the decimal point.

478. To estimate carbonic acid a standard liquid containing a definite amount of suspended barium carbonate is used for comparison. The glasses are placed side by side in the comparison box, with the black slide in the back. The passage of the gas should be interrupted and the test-glass slightly shaken once or twice to wash down any particles of carbonate which may adhere to the sides of the glass above the surface of the liquid. This shaking can be done sufficiently without disconnecting the test-glass. The standard should also be shaken before the comparison is made, in order that the precipitates may be in a similar condition. When the two liquids are judged to be equally white and

opaque, the volume of water in the measuring cylinder gives the volume of gas which has precipitated a known weight of barium carbonate. Table II. gives the relation between (V) the divisions of the large measuring cylinder filled with water and (C) the volume of carbonic acid in 100 volumes of gas. When the gas contains more than .72 per cent. of carbonic acid the smaller measuring cylinder should be used, and the values of C multiplied by moving the decimal point one place to the right.

TABLE II.

V.	C.	V.	C.	V.	C.	V.	C.
10	.72	33	.22	56	.13	79	.09
11	.65	34	.21	57	.13	80	.09
12	.60	35	.21	58	.12	81	.09
13	.55	36	.20	59	.12	82	.09
14	.51	37	.20	60	.12	83	.09
15	.48	38	.19	61	.12	84	.09
16	.45	39	.18	62	.11	85	.08
17	.42	40	.18	63	.11	86	.08
18	.40	41	.17	64	.11	87	.08
19	.38	42	.17	65	.11	88	.08
20	.36	43	.17	66	.11	89	.08
21	.34	44	.16	67	.11	90	.08
22	.33	45	.16	68	.11	91	.08
23	.31	46	.16	69	.10	92	.08
24	.30	47	.15	70	.10	93	.08
25	.29	48	.15	71	.10	94	.08
26	.28	49	.15	72	.10	95	.08
27	.27	50	.14	73	.10	96	.07
28	.26	51	.14	74	.10	97	.07
29	.25	52	.14	75	.10	98	.07
30	.24	53	.14	76	.09	99	.07
31	.23	54	.13	77	.09	100	.07
32	.22	55	.13	78	.09	150	.05

479. After each testing the glass and capillary tube should be cleaned with a little *dilute* hydrochloric acid, and well rinsed with distilled water. The turbid liquid is poured into a flask, which should be kept well corked, containing an excess of crystallised barium hydrate. After the suspended precipitate has subsided the clear liquid is poured off, or, if necessary, filtered, into another flask, also kept well corked, from which it may be poured into the test-glass when required. Care should be taken not to expose the solution to the air longer than necessary.

480. The burner part of the apparatus is also made in



FIG. 64.—HARCOURT BURNER (IMPROVED).



FIG. 65.—HARCOURT BURNER (MARSHALL'S IMPROVEMENT).

the modified forms shown in Figs. 64 and 65. Fig. 64 shows the burner as illustrated in Fig. 63, but with a dry governor, *G*, to control the gas supply to the burner *below the bulb*. Fig. 64 shows Mr. F. D. Marshall's improvement, by which the bulb is enclosed in copper chamber, *H*, surmounted with a cover in which is fitted a suitable thermometer, *T*, which is heated by a Bunsen burner, *B*. A dry governor is also provided. This arrangement effectually protects the bulb from fusion or fracture, while at the

same time it enables the operator to ascertain the temperature necessary for the conversion of CS_2 into H_2S . Mr. Leicester Greville has devised a combined measure and aspirator for use with this test, instead of the separate $\frac{1}{16}$ th and $\frac{1}{16}$ th cubic-foot measures described above.

481. *Leicester Greville's rapid test for H_2S* is an arrangement by which the H_2S in gas is arrested in a solution of ammonia and the amount estimated by titration with an ammoniacal copper sulphate solution of a known equivalent to H_2S which it reacts upon and forms into copper sulphide. This test and a similar one for estimating H_2S and CO_2 in gas liquor were communicated by Mr. Greville to the *Journal of Gas Lighting* of June 23, 1896, and November 20, 1900, from which the following particulars are taken. The test for gas liquor is described in Chapter IX; for ascertaining H_2S in gas proceed as follows:

482. Dissolve 46.7 grains clean metallic copper (in the form of thin foil or wire) in a slight excess of nitric acid, being careful to prevent spurting. When dissolved dilute with a small quantity of water, and add such an excess of liquid ammonia that the precipitate at first formed is perfectly dissolved with the formation of a clear blue solution. Dilute with distilled water, making up to 500 cubic centimetres ($\frac{1}{2}$ litre). *The solution will be of such a strength that 1 cubic centimetre equals 0.05 grain sulphuretted hydrogen (H_2S).*

483. The gas is passed into the Harcourt Colour Test Tubes, as in paragraph 477 (the burner being dispensed with). The first tube is charged with a solution of ammonia and distilled water (1 volume NH_3 to 10 volumes of water); and the second tube is charged with distilled water. At the outlet of the second tube is placed a lead acetate paper, as a check on the total absorption of the H_2S . The gas can be passed, being measured by a meter or aspirator, until one-

tenth of a foot has been used. The contents of the two tubes are emptied into a white porcelain basin and titrated with the ammoniacal copper sulphate solution.

484. When the copper solution, which is placed in a 100 cubic centimetre burette, quantity being noted, is allowed to drop slowly at first (the contents of the basin being stirred) a slight brown tint will appear, and the reaction is complete when the black copper sulphide has separated and been allowed to settle down, leaving a colourless, supernatant liquid. If too much solution has been added this will be shown by a slight blue tint, and a second test must be made; but a little experience will prevent this.

Now 1 c.c. copper solution = 0.05 grain H_2S , and $\frac{1}{10}$ th cubic foot has been used.

Presume 11 c.c. were necessary in order to complete reaction.

Then the amount of H_2S (in grains) per 100 cubic feet will be:

$0.05 \times 11 \times 10 \times 100 = 550$ grains;
or, the number of c.c. used multiplied by 50 and counted as whole numbers gives the same result:

$50 \times 11 = 550$ grains per 100 cubic feet.

485. Mr. Leicester Greville states that the test is very simple (which will be evident from the description) and accurate, which Mr. Greville proves by showing a comparison between a test made as above and a test made by a gravimetric method. A test can be made in less than five minutes if the necessary solution is at hand.

486. *Young's Rapid Sulphur Test.*—In the earlier editions of this book Mr. Hartley described a test for sulphur in purified gas devised by Mr. W. C. Young, and the description is reproduced here with an extended explanation.

487. In the liquor given by the Referees' apparatus (Chapter V) there are present carbonate of ammonium and sulphate of ammonium. Before converting the latter com-

pound into sulphate of barium it is necessary to decompose the former, which is effected by boiling the liquid with an excess of hydrochloric acid, chloride of barium being afterwards added. There is then present the excess of chloride of barium, hydrochloric acid, chloride of ammonium, and sulphate of barium.

488. Now, as hydrochloric acid and chloride of ammonium are readily volatile, whereas chloride of barium is not, it follows that, if the quantity added of the latter be known, then the amount left after volatilising the two former must be the excess of chloride of barium added, the difference being clearly due to the chloride of barium required to decompose the sulphate of ammonium.

489. The method adopted is to add to the liquid products a *known* quantity of barium chloride, and having expelled the hydrochloric acid and chloride of ammonium, to titrate the remainder with a solution of silver nitrate, which has a known equivalence to barium chloride. In this way the amount uncombined with the sulphur is found, and therefore the amount which has combined with sulphur, forming barium sulphate, is also found, from which the amount of sulphur is ascertained.

490. The apparatus is used in the ordinary way, excepting that an upright eduction-tube 12 inches long is employed, in order that the bulk of the liquor obtained may be small. If 10 cubic feet have been burned the liquor and washings are made up to 500 septems (half a decigallon), well mixed, and 25 septems ($\frac{1}{4}$ th part), measured by a pipette for the experiment. To this is added a slight excess of acetic acid (two drops are generally sufficient) and 10 septems, measured by a pipette, of a standard solution of chloride of barium, containing 1625 grains in one gallon. The whole is then transferred to a shallow, flat-bottomed platinum capsule, and evaporated to dryness over a burner. The evap-

oration can be conducted over an Argand or rose Bunsen burner, the heat being adjusted so as to keep the liquid just below boiling, and so prevent possible spurting; but, where a number of estimations are being made simultaneously, it is best done on a water or steam bath. After evaporating to dryness the residue is gently heated until the crucible is at a slight red heat; it is then cooled and the contents washed out with water into a small beaker. To this solution an excess of yellow chromate of potassium is then added, and a standard solution of nitrate of silver, containing 531.2 grains per gallon, is added from a burette containing 50 septems (graduated into fifths of a septem), until a permanent change of tint is observable on shaking the liquid.

491. *Each septem left in the burette indicates one grain of sulphur per 100 cubic feet of gas, and each division .2 grain, as will be seen from the following:*

492. The strengths of the two solutions employed are such that

$$\begin{aligned}
 1 \text{ septem } \text{AgNO}_3 &= 0.2 \text{ septem } \text{BaCl}_2. \\
 \text{Now } 1 \text{ septem } \text{BaCl}_2 &= \frac{1625}{10000} \text{ grains (1 septem = } \frac{1}{10000} \text{ gallons).} \\
 \therefore 1 \text{ septem } \text{AgNO}_3 &= .1625 \times .2 = .0325 \text{ grains } \text{BaCl}_2. \\
 \text{Now the combining proportions of sulphur and } \text{BaCl}_2 &\text{ are} \\
 &\text{as 32 is to 208, or 2 to 13.} \\
 \therefore \text{The amount of sulphur represented by .0325 grains} & \\
 \text{BaCl}_2 \text{ is } \frac{.0325 \times 2}{13} &= .005 \text{ grains.}
 \end{aligned}$$

That is to say, the amount of sulphur represented by each uncombined septem of $\text{AgNO}_3 = .005$ grains.

And $\frac{1}{10}$ th of the products of 10 feet were operated upon,
 $\therefore .005 \times 20 \times 10 = 1$ grain per 100 cubic feet.

In other words, each septem of AgNO_3 left in the burette

indicates that its equivalent of BaCl_2 has combined with sulphur according to their combining weights as above, and from the figures it is seen that each septem of AgNO_3 uncombined equals 1 grain sulphur per 100 feet of gas.

493. When a solution of nitrate of silver is added to a mixture of soluble chromate and chloride there is produced at first a deep red precipitate of chromate of silver, which is immediately converted into the white chloride of silver, the colour at once disappearing. This action goes on until the whole of the chlorides present have been precipitated, and then the deep red chromate of silver formed is unaffected, and so marked is the change in the colour that one drop in excess of the standard solution of nitrate of silver employed in this process produces such a decided red tinge that no one could be mistaken. This one drop would introduce an error of less than .2 grain of sulphur per 100 cubic feet of gas.

494. The process of evaporation, as directed, takes at the most fifteen minutes, the rest of the work needing a few moments more. Should the result of a test appear at all extraordinary, it can readily be checked by a repetition, or by a separate gravimetric estimation, as only a very small quantity of the liquid is used.

495. Should the gas contain more than 50 grains of sulphur per 100 cubic feet, it will be necessary to make the bulk of the liquor up to one decigallon (twice the quantity before directed); proceed as usual, and multiply the number of septems of standard nitrate of silver solution remaining by two to find the amount of sulphur present.

496. If a "short" test is desired one-half of a cubic foot should be burnt, when, if the whole of the liquor be taken, the number of septems of standard nitrate of silver solution remaining will indicate the number of grains of sulphur per 100 cubic feet.

497. *Wanklyn's Test for Sulphuretted Hydrogen in Crude Gas.*—This test was devised by J. Alfred Wanklyn, and described by him in his "Gas Engineer's Chemical Manual." The apparatus employed is the $\frac{1}{16}$ th of a cubic foot gas-bottle, with hollow stopper; a burette, or an alkali-meter, of one or two fluid ounces' capacity, and graduated into divisions of $\frac{1}{16}$ th of a fluid ounce. (See Fig. 66.) The standard acetate of lead solution used in this test is made by dissolving 28.56 grains of crystallised acetate of lead in 1

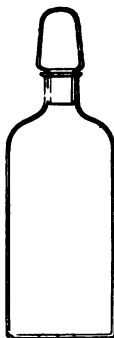


FIG. 66.—WANKLYN BOTTLE.

decigallon (16 fluid ounces) of distilled water. Each $\frac{1}{16}$ th ounce of the solution precipitates $\frac{1}{16}$ th part of a grain of sulphuretted hydrogen; and, employed with the gas-bottle full of gas, each $\frac{1}{16}$ th ounce, or each division of standard solution, corresponds to 10 grains of sulphuretted hydrogen per 100 cubic feet of the gas. Slips of white bibulous paper impregnated with acetate of lead are used as an indicator, the cessation of the blackening of the slips, when pushed up into the bottle, being the indication that sufficient lead solution has been applied to the $\frac{1}{16}$ th cubic foot of gas.

498. The manner of testing is illustrated by an example:

The *dry* gas-bottle is filled with gas by displacement, 20 divisions of lead-solution are dropped into the hollow

stopper, which is then inserted into the neck of the gas-bottle. Several shakes are given to the bottle, which is then inverted and the liquid allowed to drain down the sides of the bottle into the stopper; the latter is then taken out and a slip of lead-paper pushed up into the bottle; the lead-paper is deeply blackened. Eight divisions of lead-solution are added to the liquid in the stopper and shaken up with the gas. A trial with lead-paper shows darkening of the paper. Two more divisions of lead-solution are shaken up with the gas; this time the lead-paper is not nearly so dark. One division of the lead-solution is added and the bottle shaken; the lead-paper is only faintly stained. One more division of solution added, the bottle shaken, and the inserted lead-paper fails to show any stain. Thus, 31 divisions of lead-solution is too little and 32 divisions too much; 31.5 divisions is, therefore, taken as the quantity necessary to combine with the H_2S in the gas. Now, as each division of solution precipitates $\frac{1}{1000}$ th part of a grain of H_2S , the quantity of H_2S precipitated by the 31.5 divisions of solution will be 31.5 hundredths of a grain ($= \frac{31.5}{1000}$ grain) for the $\frac{1}{100}$ th cubic foot of gas; and $\frac{31.5}{1000} \times 1000 = 31.5$ grains of H_2S per 100 cubic feet of gas.

This result may be most simply accomplished by noting the number of divisions of solution used, and multiplying that number by 10.

31.5 divisions of solution $\times 10 = 315$ grains of H_2S per 100 cubic feet of the gas.

499. Lacey's Rapid Test for Ammonia in Purified Gas is one which will be of great service to gas managers, as the following facts will show:

When gas companies are under restrictions as to the maximum amount of ammonia (and sulphur) that the purified gas shall contain, it may often become necessary for the engineer or manager of a gas works to ascertain the quantities of those impurities as quickly as possible; especially is this necessary when a temporary break-down in the washing-plant on the works takes place. These cannot be determined readily enough by the Gas Referees' methods. T. S. Lacey (Pimlico, London, S. W.) has devised a method by which the ammonia in either the crude or the purified gas can be determined in about ten minutes.

500. Two standard test-solutions are used, one being a sulphuric acid solution and the other a solution of ammonia, prepared to correspond with the former one.

The standard sulphuric acid solution may be prepared by diluting the ordinary standard acid solution (as prescribed and used by the Gas Referees) one hundred times with distilled water. Measure out 10 septems of the Gas Referees' standard sulphuric acid solution and make up to one decigallon with distilled water; or, if a larger quantity be desired, measure out 100 septems of the above-mentioned sulphuric acid solution and make up to one gallon with distilled water. Thoroughly mix. 25 septems of such solution are equivalent to the one-hundredth of a grain of ammonia.

The standard ammonia solution also requires to be diluted to the same extent as the acid solution. After diluting and thoroughly mixing this solution it must be checked, to ascertain whether 100 septems of the test-alkali thus prepared will neutralise 25 septems of the test-acid, prepared as above.

100 septems of this ammonia solution contain the one-hundredth of a grain of ammonia.

501. The apparatus employed is shown in Fig. 67, and consists of a 25-septem pipette, a modified form of Wank-

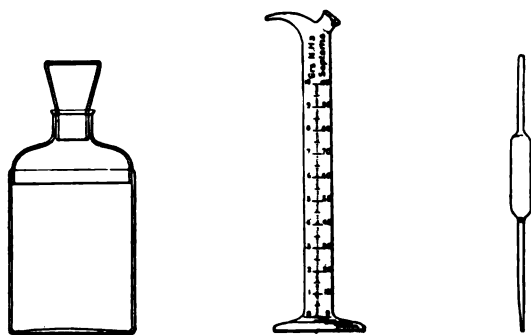


FIG. 67.—WANKLYN BOTTLE (IMPROVED), WITH BURETTE AND PIPETTE.

lyn's gas-bottle, arranged so that the hand can be inserted for drying, and having a capacity of $\frac{1}{10}$ th cubic foot, the

hollow stopper being made with a flat top to facilitate handling; and an alkalimeter for measuring the ammonia solution during the titration of excess acid. The alkalimeter has a capacity of 100 septems from top mark to the bottom mark, and is subdivided into septems and half septems, each 10 septems being numbered; opposite these numbers 0 to 100 are other numbers 0 to 10, representing grains of ammonia per 100 cubic feet, when used with the $\frac{1}{10}$ th cubic foot gas-bottle; each septem is, therefore, equivalent to $\frac{1}{10}$ th grain NH_3 per 100 cubic feet of gas. It is important that the gas-bottle used should be the form shown, as it is absolutely necessary to clean and dry the bottle before a test is made, and this is not easily accomplished with the ordinary form.

502. *To Make a Test.*—Take a clean and dry gas-bottle and fill this vessel with the gas to be examined by downward displacement of the air, the vessel, of course, being inverted. Now into the hollow stopper let fall 25 septems of the test-acid solution, measured by means of the pipette, and add one or two drops of a tincture of cochineal, which will be turned an orange colour by the test-acid. (Cochineal is to be preferred to litmus, because the latter is rendered valueless in the presence of carbon dioxide and sulphuretted hydrogen.) Into the neck of the still inverted gas-bottle insert the stopper and contents, and bring the liquid into intimate contact with the enclosed gas by shaking. After about a minute or so transfer the liquid to a small beaker; wash out the gas-bottle and stopper with about 25 septems of distilled water, and add the washings to the acid liquor in the beaker. The contents of the beaker contain the ammonia absorbed from the one-tenth of a cubic foot of the gas. The excess of test-acid must now be titrated with the test-alkali. Fill the alkalimeter up to the top mark with the ammonia solution, prepared as directed; place the thumb over the larger opening

while holding the alkalimeter, and allow the test-alkali to fall into the beaker containing the acid liquid, in small quantities at a time, and well stirring between each addition, until it is seen that the liquid has resumed a magenta colour, indicating that the excess of acid is neutralised by the ammonia added from the alkalimeter. Now place the alkalimeter on its foot in an upright position and wait until the liquid has finished running down the sides of the interior, then the quantity of test-alkali remaining will at once show the amount of ammonia in grains contained in 100 cubic feet of the gas.

503. Suppose that, after titration, there remained 12 septems of the test-alkali, then, as each septem is equivalent to a tenth of a grain of ammonia per 100 cubic feet of gas, the 12 septems will represent 1.2 grains as the amount of ammonia per 100 cubic feet of the gas.

504. As will be seen from the alkalimeter, this method is suitable for use with gas containing a maximum of 10 grains of ammonia per 100 cubic feet of gas, but may be used to test gas containing amounts varying from 10 to 20 grains; in that case another 25 septems of the test-acid solution is employed in the gas-bottle, making 50 septems in all. When the gas contains more than 10 grains per cubic feet, the tincture of cochineal added with the first 25 septems will not be changed to an orange colour, but to a violet colour. Suppose that the 50 septems of test-acid have been run into the gas-bottle, and after neutralisation it was found that 39 septems of test-ammonia solution remained in the alkalimeter, then the amount of ammonia in 100 cubic feet of the gas would be $10 + 3.9 = 13.9$ grains.

Test for Ammonia in Crude, or Unpurified, Gas.

505. It may be required by some engineers or managers

to know the amount of ammonia absorbed by a certain washer or scrubber on the gas-works; this can be obtained by testing the gas before and after passing through the washing vessel. The method of testing is similar to that as described for ammonia in purified gas, but the test-acid and alkali employed are of greater strength than those used and described in the previous test. The test-sulphuric acid solution is prepared by diluting the Gas Referees' ordinary test-acid solution to one-fourth its strength. Measure out 250 septems of the Gas Referees' test-acid solution and make up to one deci-gallon with distilled water; or for a larger quantity, measure out 2500 septems ($= 2\frac{1}{2}$ deci-gallons) of the Gas Referees' test-acid and make up to one gallon with distilled water. 100 septems of such solution are equivalent to one grain of ammonia. The test-ammonia solution employed is that prescribed and used by the Gas Referees for their ammonia-in-purified-gas-test. 100 septems of this solution contain one grain of ammonia, and are equivalent to 100 septems of the test-acid solution as prepared above.

506. The apparatus employed is the 25-septems pipette; the one-tenth of a cubic foot gas-bottle, and a 25-septems alkalimeter graduated as shown in Fig. 68. Septems are engraved on one side, and grains on the other side of the alkalimeter. Each septem represents 10 grains of ammonia per 100 cubic feet of the gas, when used with the one-tenth of a cubic foot gas-bottle.

507. *To Make a Test.*—Fill the gas-bottle with the gas to be examined; measure out into the hollow stopper 25 septems of the test-acid solution, and add one or two drops of a tincture of cochineal; insert the hollow stopper, and shake up the contents with the enclosed gas. If, after a minute or two, the liquid contents are still of an orange colour an excess of the acid-solution has been used, but if the colour has changed to a violet, then there is an excess of ammonia

within the gas-bottle and another 25 septems of the test-acid must be introduced, and the whole again shaken up until it is found that the liquid contents in the gas-bottle are of a permanent orange colour. Now transfer the liquid contents to a small beaker, wash out the gas-bottle with about 25 septems of distilled water, and add the washings to the contents of the beaker. The excess of test-acid is

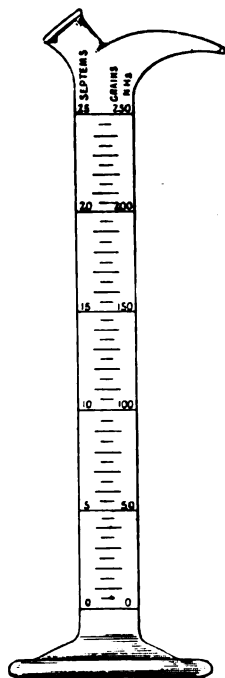


FIG. 68.—BURETTE FOR LACEY'S NH_3 TEST.

now to be titrated with the test-alkali as prepared for this test. Proceed as before, but employ the alkalimeter, Fig. 68. When the acid is neutralised by the test-ammonia solution, an observation of the amount of this solution remaining in the alkalimeter will at once show the quantity of am-

monia in grains per 100 cubic feet of the gas. If more than one charge of the alkalimeter be used, then the result will be 250 grains plus the number of grains equivalent to the amount of test-solution left in the measure after the second charge.

508. It is to be understood that when taking the sample of gas the gas-bottle must be quite dry, otherwise the ammonia in the gas will saturate the water clinging to the sides of the bottle and the results obtained will be much too high.

Estimation of Naphthalene in Coal-Gas.

509. It may be desired to test gas for naphthalene, either qualitatively for its presence or quantitatively for its amount. The following tests were communicated by Dr. H. Colman and Mr. J. F. Smith to the Nottingham Section of the Society of Chemical Industry in February, 1900. The tests are based upon the fact that picric acid combines with naphthalene, forming naphthalene picrate, formula of which is $C_{10}H_8, C_6H_3N_3O_7$, and which is scarcely soluble in aqueous picric acid.

510. *To Make a Test for the Presence of Naphthalene.*—A solution of the acid of the strength given below is taken and two or three cubic feet of gas are passed through it. If no precipitate is formed it may be taken that the gas only contains traces of naphthalene, as one milligramme gives a perceptible precipitate.

511. *The quantitative test for naphthalene* is made as follows: A solution of picric acid is made of such a strength that it is nearly saturated at the ordinary temperature (about $\frac{1}{10}$ th normal). The strength of the solution is accurately found by titrating with $\frac{N}{10}$ baryta water, using lacmoid as an indicator, the colour of which changes from

brownish yellow to green in the presence of an excess of alkali.

512. The principle of the test is, shortly, this: that since the equivalence of the picric acid to the barium hydrate is known, and since picric acid is absorbed by naphthalene, the difference between the quantity of barium hydrate required to neutralise the acid before and after it has been brought into contact with the naphthalene gives the quantity of acid formed into naphthalene picrate, and from this the quantity of naphthalene is deduced.

513. For the absorption of the naphthalene a series of four bottles is employed, the first of which has a capacity of about 300 cubic centimetres, and contains 100 cubic centimetres of picric acid solution, and the second and third are small bottles, each containing 50 cubic centimetres; the fourth bottle is empty, and serves to retain any splashings of picric acid solution from the other bottles, the gas passing thence to the meter. The gas is bubbled through at the rate of 0.5 to 1 cubic foot per hour, until 10 to 15 feet have been passed. As a rule, the whole of the naphthalene is retained in the first bottle, the liquid in the other bottles remaining quite clear. It is, however, possible that in very warm weather, or if the test is carried out in a very warm room, this might no longer be the case, and it would then perhaps be advisable to add a fourth bottle of solution. After the gas has been shut off the contents of the second and third bottles are transferred to the first, the solution being washed out from the former with as small a quantity of water as possible.

514. Küster's method of procedure is then closely followed. The bottle is closed with an india-rubber stopper, through which passes a glass tube closed at the lower end, but having a small hole blown in the side about an inch from the bottom. The tube is placed so that this hole is just

below the bottom of the stopper, and the bottle then evacuated as completely as possible with a water-jet pump; while the pump is still working the tube is raised so that the small hole is well above the bottom of the stopper, the bottle being thus sealed. It is then placed in a water bath containing sufficient water to cover it, the water heated to the boiling-point, and the heating continued until the liquid is quite clear. The bottle is then removed and allowed to cool, with occasional shaking to wash down any naphthalene which may sublime on to the upper portion of the bottle. After standing for some time, preferably over night, the naphthalene picrate separates out completely, and is then filtered off on the pump and the precipitate washed with a small quantity of water. (If much water is used too low results are obtained, as although naphthalene picrate is scarcely soluble in picric acid solution, it dissolves appreciably in water, 100 cubic centimetres of the latter dissolving 0.1857 gramme at 14°.) The combined filtrate and washings are made up to 500 cubic centimetres, well mixed, and 100 cubic centimetres titrated with decinormal caustic soda or baryta water.

515. From these data the quantity of picric acid which has combined with the naphthalene can be readily calculated. Naphthalene picrate has the formula $C_{10}H_8, C_6H_3N_3O_7$, i. e., 229 parts of picric acid are united with 128 parts of naphthalene, and therefore the quantity of picric acid thus found multiplied by $\frac{128}{229} = 0.559$ gives the quantity of naphthalene in the volume of gas passed. For technical purposes it is most convenient to calculate the result to grains of naphthalene per 100 cubic feet of gas.

516. To prove that the other hydrocarbons contained in coal-gas are not absorbed by picric acid in a manner which affects the test, a sample of the hydrocarbons present in the gas along with naphthalene, and boiling at a lower tem-

perature, was made by carefully fractionating the portion of coal-tar boiling below 200° C. until it was completely free from naphthalene. Air was then passed over 4.86 grammes of this liquid heated to 50° C. until it had disappeared, and the resulting gas passed through picric acid solution; on working out the test it was found that only 0.001 gramme of picric acid had been precipitated, a quantity which is within the limits of experimental error. Any higher-boiling hydrocarbons in the gas which form stable picrates (such as the methylnaphthalenes) would, however, be precipitated, and would therefore be recorded as naphthalene in the test.

517. The ordinary gas pressure is not sufficient to force the gas through the series of bottles used for the test, but where the full gasholder pressure can be utilised this will generally be sufficient. If this is not available, the pressure may be increased by means of a water-jet pump; but this has the disadvantage that the gas is washed with a large volume of water, which might remove some of the naphthalene. The authors, therefore, prefer the following arrangement, which can also be employed for any tests where higher pressure is required, and also for making tests such as estimation of ammonia, etc., in the crude gas before the exhaustor, where it is under less than atmospheric pressure. (See Fig. 69.)

518. The method consists in enclosing the meter in a stout case of galvanised iron, the top of which can be closed air-tight by means of suitable clamps and packing, and having a piece of plate-glass fixed in the front to allow of the meter index being read off. The inlet of the meter is connected by means of a union to a tube passing outside the meter case, which is connected by a flexible tube to the testing apparatus, the outlet of the meter remaining open. On the cover are three tubes, *a*, *b*, *c*, and a fourth, not shown in the figure, which is connected to the mercury pressure gauge.

The tube *a* is connected to a small steam or water-jet vacuum pump, and *b* and *c* to the pressure regulator. When the pump is started and the air drawn from the meter case the mercury level rises in the right-hand limb of the U-tube, *B*, and falls in the left limb, this continuing until the level in the latter is below the bottom of the tube, *C*. As soon as this occurs air is drawn into the meter case through the side tube, *D*, and vertical tube, *C*, so that the vacuum cannot then rise higher. Any desired amount of vacuum

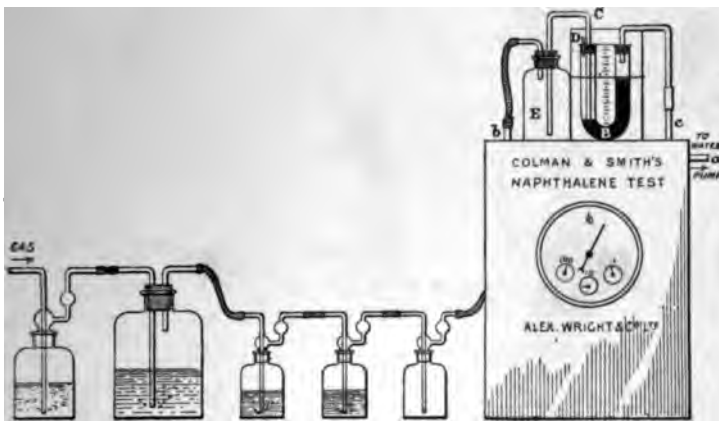


FIG. 69.—APPARATUS FOR ESTIMATING NAPHTHALENE IN GAS
(COLMAN AND SMITH).

can be obtained by simply regulating the height of tube, *C*, and so long as the pump exhausts gas more quickly than it passes in through the meter or through any leaks in the case this vacuum is constantly maintained. The bottle, *E*, is interposed to catch any globules of mercury which may be carried over with the current of air. With this apparatus, therefore, the pressure around the meter can readily be regulated to any desired amount below that of the atmosphere, and a vacuum of 2 inches of mercury (= 27 inches of water) is amply sufficient to draw the gas through any test-



ing apparatus, even if the gas itself is under the vacuum of 12 inches of water.

519. In making the usual correction of the volume of gas registered by the meter for temperature and pressure, the amount of vacuum shown on the mercury pressure gauge, must be deducted from the reading of the barometer, as this represents the difference between the atmospheric pressure and that within the meter case.

Since the above was written the authors of the test have arranged a simple modification for the elimination of calculations, and have prepared a concise but ample set of instructions. The manufacture of the test has been placed in the hands of Alex Wright & Co., Ltd., Westminster.

[NOTE.—Pars. 520-549 are left blank to facilitate additions in a future edition.]

CHAPTER IX.

TESTING BYE-PRODUCTS.

550. As many of the bye-products from the process of gas manufacture have a commercial value, it is usual to test them for the proportion of their valuable constituents. The principal tests of interest to a gas-works manager are described below, and for the complete examination of the many hundreds of products from the destructive distillation of coal, other special books must be consulted.

551. *Coke*.—It may be required to examine this for its sulphur, moisture and ash, and also for its calorific power. The methods are described in the chapter on "Coal," which see.

552. *Gas Liquor*.—Since ammoniacal liquor, or gas liquor (for the composition of which see par. 557) is a product of commercial value and is sold by its strength, it is necessary that the liquor be tested for its strength in a manner agreed upon between buyer and seller. There are several of these methods in daily use, and these are detailed below. It should be noted, however, that the liquor is sold according to its "*ounce strength*," which means the number of ounces by weight of mono-hydrated sulphuric acid, H_2SO_4 , which is required to saturate one gallon.

553. *Hydrometer Test for Strength of Gas Liquor*.—The crudest method by which the strength of liquor is determined is based on the assumption that the quantity of acid required to saturate the liquor bears a certain relation to the gravity of the latter. In this method a No. 1 Twaddle's hydrometer

is employed, having a scale divided and numbered from zero at the top to 25 at the lower part of its stem. A suitable glass jar having been charged with liquor, which should be at the temperature of 60° Fahr., the hydrometer is immersed as shown in figure J in Fig. 70, and the scale line to which it sinks in the liquor observed. The accepted rule is that each degree of the scale indicates the presence of as much ammonia in one gallon of the liquor as will require *two* ounces by weight of sulphuric acid of the strength above mentioned. Thus, if the hydrometer sinks to the line 4 on the scale, the liquor is taken to be of 8-ounce strength. It may be mentioned that each degree of Twaddle's hydrometer is equal to *five* degrees of gravity or density in 1000. Hence, to find the actual gravity of any fluid by this instrument it is necessary to multiply the scale indications by 5, and add the product to 1000. Example.—Depth of immersion, say, to line 4 on the scale, then $4 \times 5 = 20$, which, added to 1000, equals the specific gravity, viz., 1.020.

554. *Alkalimeter Test for Strength.*—By the second usual method, an experimental trial is made to find the number of ounces H_2SO_4 which is needed to saturate and neutralise the ammonia in one gallon of liquor; but as it is not convenient to operate on so large a quantity, nor to use concentrated acid, an alkalimeter, Fig. K, is employed, and a solution of H_2SO_4 consisting of one pound of the acid, specific gravity 1.845, united with sufficient water to measure exactly one gallon at 60° Fahr. The specific gravity of such solution should be, according to Mr. A. Vernon Harcourt, 1.064.3. By an error in expression, the solution so made came to be called *ten per cent.* acid, and its gravity was also erroneously stated in some publications to be 1.068.2, which is the gravity of a solution composed of one pound of concentrated acid and nine pounds of water.

555. The following is an extract from a letter written by

Mr. Hartley to the *Journal of Gas Lighting* on the subject of the strength of the solution :

"The volumes of equal weights of fluids are, of course, inversely as their gravities or densities; therefore, the relative bulks of acid of 1846 gr. (to adopt Ure's

figures) and water must be $\frac{1000}{1846}$, or .542 to 1. Hence,

so far as mere calculation goes, a gallon of test sulphuric acid composed of 1 pound H_2SO_4 with water enough to make up one gallon, should contain—

Sulphuric acid	0.542 parts.
Water	9.458 "

Theoretical volume	10.000 parts.
--------------------------	---------------

While the weights must in the above mixture be—

Sulphuric acid	1.000 lbs.
Water	9.458 "

Theoretical weight for one gal-

lon	10.458 lbs.
-----------	-------------

And this divided by 10 (the weight in pounds of a gallon of water) gives a theoretical gravity of 1045.8; but *experiment* effectually disposed of conclusions so arrived at. I made a mixture of—

Sulphuric acid (H_2SO_4), 700 grains, or	54.17 septems.
Water, $700 \times 9 = 6300$, or	900.00 "

Theoretical volume of mixture 954.17 septems. But, when cooled to 60° Fahr., it really measured about 935 septems, thus showing a contraction in volume of about 2 per cent., or 0.1 per cent in excess of the contractions due according to the gravity of such mixture by Ure's table. In order to make up the volume to a decigallon (1000 septems) I was obliged to add 64 septems of water. Hence, the decigallon consisted of 964 septems or 6748 grains of water and 700 grains of acid, together weighing 7448 grains, which divided by the weight (7000 grains) of a decigallon of water, gave the gravity as 1064. Further experiments, in which the strength of the mixtures was determined by the sulphate produced on the addition of chloride of barium to a given volume of the dilute acid, led me ultimately to fix upon 1063.5 as the

gravity at 60° Fahr. The relation of the true volume of such acid to the theoretic volume must be $\frac{1045.8}{1063.5}$, or as 981.57 to 1000.

“Thus, while the volume of acid (H_2SO_4) which must be added to a given volume of water, in order to produce a dilute acid containing a certain percentage by weight of H_2SO_4 , may be readily calculated, it is apparently impossible to predicate the volume of the produced mixture, and therefore its gravity. A few examples will show this. Sulphuric acid solutions of the percentage strength by weight given in the following table must contain—

	10 per Cent. Acid	30 per Cent. Acid	50 per Cent. Acid	90 per Cent. Acid
H_2SO_4	.541	1.6251	2.703	4.874
Water.....	9.000	7.0000	5.000	1.000
Theoretical volume.....	9.541	8.6251	7.703	5.874
Theoretical specific gravity	1048.2	1159.4	1298.2	1702
Actual specific gravity per Ure.....	1068.2	1218.4	1388.4	1807
Relation of actual to theoretic volume.... }	981 to 1000	951 to 1000	935 to 1000	942 to 1000

“It will be observed that there appears to be no regular contraction in volume; for while the difference between the actual and theoretical volume is with the 50 per cent. acid nearly 7 per cent., it is with the 90 per cent. acid but little over 6 per cent.

“Such are the evidences afforded by experimental facts and (as I believe) correct reasoning, and I put these statements forward with the hope that they may help to clear away any confusion of understanding as to what is or is not the test-acid which is volumetrically correct. At the present moment persons are using true volumetric instruments (alkalimeters), and utterly ignoring and neglecting the primary principle or condition upon which they are based—namely, that the testing acid for ammoniacal

liquor should contain 16 ounces of H_2SO_4 in one gallon.

"Ten per cent. acid, of course, makes ammoniacal liquor appear *below* its real strength and value, and certainly every vendor of liquor *ought* to know its *actual* strength, and indeed, if possible, the absolute quantity of ammonia contained in it."

556. The method of testing with the acid solution is as follows: Charge the alkalimeter with liquor up to the top line of the graduations. Then transfer its contents to a glass or porcelain basin. Rinse the alkalimeter with clean water (better, distilled water), and add the rinsings to the contents of the basin. Next rinse the alkalimeter with a little of the test acid solution and pour the rinsings away, after which charge it with acid solution to the top line. It is better to use two alkalimeters of exactly equal capacity, one for liquor and the other for acid. Pour the solution by degrees into the liquor in the basin, well stirring between each addition, and when effervescence has nearly ceased on the addition of acid, drop in a piece of blue litmus paper, and if this continues blue in colour add more acid in small portions, well stirring the whole time, until the paper assumes a slightly red tint. It may be necessary to use several pieces of test paper, as the sulphuretted hydrogen evolved tends to bleach the paper. See how much acid has been used from the alkalimeter; suppose it be a quantity equal to eight divisions down the scale, the liquor is indicated to be 8-ounce strength. To prevent the acid running down the outside of the alkalimeter, slightly grease the delivery point before pouring out the acid. In order to render the subject quite clear, it is as well to remark that the alkalimeter being divided into 16 parts, each part represents such a proportion of acid solution as would contain one ounce of the concentrated acid, while its total contents represent one gallon. It is used first to measure the liquor, and afterward to measure the acid

solution; and under such conditions it matters not, within certain limits, what its capacity may be.

557. It should be here stated that ammonia exists in gas liquor in two forms, viz., volatile, or "free," and "fixed." By "free" is not meant chemically free or uncombined ammonia, but those salts which can be decomposed by boiling, chief among these being ammonium carbonate, sulphide, cyanide, acetate. By "fixed" is meant those salts which are not decomposed by simply boiling, but which require the presence of a caustic alkali to set free the combined ammonia; such salts are the ammonium chloride, sulphocyanate, sulphate, etc.

558. Both the methods described are defective, and both fail to indicate the real quantity of ammonia in gas liquor. The hydrometer is a measure only of density, and the density of liquor is certainly not constant for equal strengths, but will vary with the different kinds of coals from which it is produced, and also, it may be, very considerably with the conditions under which the coals are carbonised. Now, a solution of "free" ammonia and water has a lesser density than water, while a liquor well charged with CO_2 has a greater density than water, so that to render the indications of the hydrometer of exact value it is actually first necessary to know the proportions of free and combined ammonia in the liquor—to know, in fact, more than a commercial test demands.

559. The second method fails, because by it the whole of the salts of ammonia in the liquor are not decomposed and resolved into sulphate. Even boiling, after apparent neutralisation when cold, and the addition of further small quantities of acid until the test papers cease to tend toward blue, or cease to retain that colour, will not succeed, although in this way the apparent strength of liquor has been raised from about 8 to $8\frac{1}{2}$ ounces. Some perfect method,

then, has been wanting by which the total quantity of ammonia may be ascertained, and such a method was devised by the late Thomas Wills, Esq., of the Royal Naval College, Greenwich, and is now used by very many gas companies with most satisfactory results.

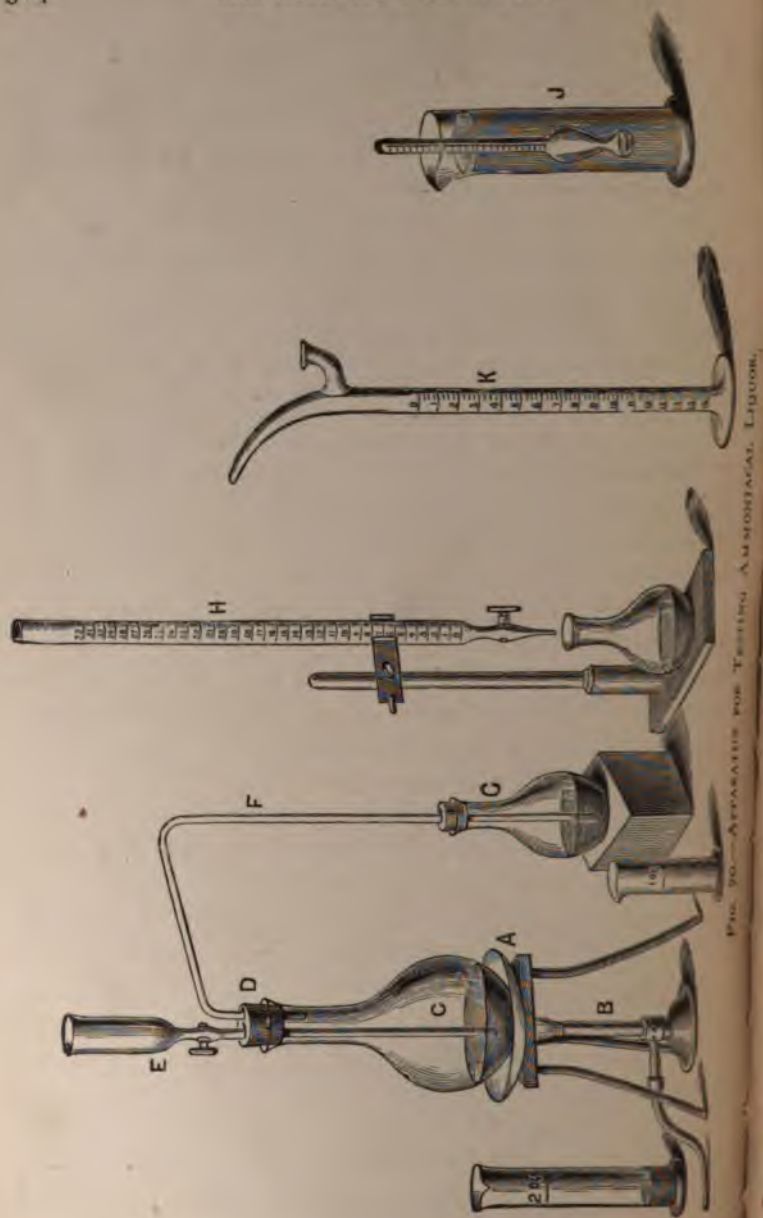
560. Will's distillation method for determining NH_3 in gas liquor, the facts upon which this method is based, are as follows:

When a mixture composed of solutions of ammoniacal salts and a sufficient quantity of some caustic alkali for which the acids of the salts have a stronger affinity than for ammonia is strongly heated for some time, the whole of the ammonia is driven off in a gaseous state, and may be secured as sulphate by bubbling into a solution of sulphuric acid; that is to say, the ammonia in the "fixed" salts is liberated and carried off with the "free" ammonia.

561. The apparatus employed consists of a sand-bath, *A* in the engraving Fig. 70, heated by means of a Bunsen burner, *B*; a flask, *C*, furnished with an india-rubber stopper, *D*, fitted with funnel, *E*, having a glass stop-cock, and also with an eduction tube, *F*; a second flask, *G*; a burette, *H*, of such capacity as to contain 2 ounces of liquid within a length divided into 32 parts, and two or three measures.

562. The solutions employed are: Pure caustic soda in the proportion by weight of 1 ounce of soda to 9 ounces of distilled water; sulphuric acid solution; ammonia of such strength as to be equivalent to the acid solution, *i. e.*, that equal measures of each when mixed shall form a solution having neither acid nor alkaline reaction on a colour test.

563. *The test-acid solution* used is of the same strength as that already mentioned. To prepare it put three pints of pure distilled water into a glass vessel which is graduated to measure half a gallon; to this add carefully half a pound (4.34 ounces by measure) of pure concentrated sulphuric



acid, specific gravity 1845, and well mix by stirring with a glass rod; cover the vessel and leave the mixture to cool down to 60° Fahr. Add *acid* to water, not *vice versa*. When this is effected add the additional quantity of distilled water to raise the volume to exactly half a gallon and again well mix. Its gravity may now be tested by a delicate hydrometer, and if more than half a degree above or below 1064.3 small additions of water or of acid must be made until the proper gravity is closely approximated. Next take exactly one measured ounce of the test-acid and add thereto sufficient of a solution of chloride of barium to combine with all the acid, as sulphate of barium, which separate by filtration, wash, ignite, and when cold weigh, in the usual manner practiced in determining the quantity of sulphur contained in coal-gas. The weight of the produced sulphate should be 104.02 grains. (See Chapter V.)

564. It is sometimes difficult to obtain a temperature of 60° Fahr. The following table, due to Mr. Lewis T. Wright, shows the specific gravity at different temperatures which the acid should have in order to correspond to the specific gravity of 1064.4 at 60° Fahr.

Temp. F.	Specific Gravity	Temp. F.	Specific Gravity	Temp. F.	Specific Gravity	Temp. F.	Specific Gravity
35	1068.85	54	1065.64	61	1064.19	68	1062.72
40	1068.10	55	1065.45	62	1063.98	69	1062.51
45	1067.30	56	1065.24	63	1063.77	70	1062.30
50	1066.40	57	1065.03	64	1063.56	75	1061.20
51	1066.21	58	1064.82	65	1063.35	80	1060.05
52	1066.02	59	1064.61	66	1063.14	85	1058.95
53	1065.83	60	1064.40	67	1062.93	90	1057.80

565. The ammonia solution may be made mixing 9.72 ounces by weight, or 11.4 ounces by measure, of con-

centrated liquor ammonia with such quantity of water as will make the total bulk half a gallon; but as liquor ammonia is generally of somewhat greater gravity than .88, and as it is easier to reduce than to increase the strength of the solution, it is better to use, say, $10\frac{1}{4}$ ounces by weight, or 12 ounces by measure, of liquor ammonia to the half gallon. To ascertain the equivalence of the ammonia solution, charge the burette with two fluid ounces of it. Take exactly one fluid ounce of the test-acid in a flask or measure and colour with a few drops of a tincture of cochineal; then draw from the burette sufficient of the ammonia solution to change the colour of the liquid from yellow to magenta. When nearly an ounce of solution has been withdrawn from the burette the further additions must be made in drops and complete mixture effected by stirring, or, if a wide-mouthed flask of about 6 ounces capacity be used as the mixing vessel, by shaking. If more or less than one ounce of the ammonia solution be required to neutralise one ounce of the test-acid, small additional quantities of ammonia or of water must be added to the remainder of the half-gallon and fresh trials made until the proper strength is attained. The bottles in which solution are stored should be filled nearly full, and be stoppered quite soundly. This is *especially* necessary with the ammonia solution, which will rapidly become weakened by exposure to the air. This solution must also be kept in a cool place.

566. *To Make a Test.*—Assuming that all the vessels are perfectly clean, that the flask, *C*, has been placed in the sand-bath as shown in the engraving, and that the junctions at *D* are perfectly gas-tight, the operations are commenced by charging the flask, *G*, with 2 fluid ounces of the test-acid. The flask is then placed in position, so that the end of the tube, *F*, is within one-eighth of an inch from the bottom of the flask. One measured ounce of liquor is next poured

into *E*, the glass cock opened to allow the liquor to fall into *C*, and then closed. On every occasion the measures employed should be rinsed with distilled water and the rinsings added to the vessels respectively which contain test-acid and ammonia liquor. One ounce of the soda solution must now be poured into *E*, the cocks again opened, and re-closed immediately after the fluid has run down into *C*. The Bunsen burner on being lighted below the sand-bath raises the contents of *C* to the boiling-point, at which they must be kept for about 15 minutes, by which time the ammonia will have passed over into and been absorbed by the test-acid in *G*. The heating flame should not be removed while the ammonia delivery tube is immersed in the standard acid, or the acid will be drawn back into the boiling flask. The crackling noise which sometimes occurs at the commencement of boiling is caused by the rapid absorption of the ammonia by the acid in the small flask, and need cause no alarm. When the ammonia has ceased to come over, the flask *G* is removed and allowed to cool, and its contents then coloured by the addition of a few drops of tincture of cochineal.

567. The burette, *H*, having been charged from zero to 32 with the test solution of ammonia, the flask *G* is placed below and the solution dropped into the flask until the liquid therein changes in colour to magenta. The addition from the burette must be made, and the flask shaken, in the manner already mentioned.

568. The strength of the liquor is indicated by the quantity of test solution *left in the burette*, which represents the quantity of ammonia which has been absorbed from the liquor by the test-acid in the flask, *G*. Thus, if 10 divisions of ammonia solution be left in the burette, the liquor is shown to contain sufficient ammonia in one gallon to saturate and neutralise 10 ounces of H_2SO_4 . That this must be the case is evident on a moment's reflection. The vol-

umes of test-acid used in the flask, *G*, and of equivalent ammonia solution contained in the burette, *H*, are *each twice* as great as the *volume of liquor* operated upon. If the liquor had been 16 ounces strength its ammonia would have neutralised just one fluid ounce, or *half* the acid employed; the remaining half would then have been neutralised by half the ammonia from the burette, or by 16 parts, and therefore 16 parts would be left and indicate the strength of the liquor. The excess of acid is employed to ensure complete absorption of the ammonia.

569. Although after boiling for some 15 minutes' time the vapour given off may colour turmeric test paper no important quantity of ammonia is lost, but to completely expel every trace of NH_3 it is necessary to evaporate to dryness; redissolve the residue with distilled water and boil again. Without this precaution the test may be depended upon to show correctly to within one-tenth of an ounce strength.

570. One important matter remains to be mentioned, viz., the correctness of the measures and burette employed: these must be in absolute agreement one with the other in measurement, otherwise grave errors will arise. Unfortunately, many of the glass measures and burettes which are made and sold are very inaccurate, and differ in capacity among themselves to the extent of 5 or 6 per cent.

571

ANALYSES OF GAS LIQUOR.

TABLE I.

Number of Sample	1	5	10	20	Averages of many Samples
Total Ammonia <i>p. cent.</i>	2.617	2.035	1.980	2.511	2.2375
Ammonia estimated by acid, <i>per cent.</i>	2.118	1.780	1.716	2.205	1.9238
Ammonia, <i>fixed, p. cent.</i>	0.499	0.255	0.264	0.306	0.3137
Total "Ounce" liquor, by <i>distillation</i>	12.06	9.38	9.13	11.58	10.3165
"Ounce" liquor, by <i>acid</i>	9.76	8.20	8.11	10.17	8.8815
"Ounce" liquor, <i>fixed</i> .	2.30	1.18	1.22	1.41	1.4350
Total Ammonia = 100 Ammonia, <i>fixed, p. ct.</i>	19.0	12.5	13.3	12.1	13.91

The table indicates that each per cent. of ammonia per gallon of liquor requires about 4.61 ounces by weight of H_2SO_4 to neutralise it. Thus, with No. 20 sample, "Ammonia estimated by acid *per cent.*" = $2.205 \times 4.61 = 10.165$ "Ounce liquor by acid" nearly, while "Ammonia fixed per cent." or $.306 \times 4.61 = 1.4007$, and these added together give "Total 'ounces' liquor by distillation" nearly, viz., 11.5657.

572. The following tables show how greatly the relative proportions of "combined" and "uncombined" ammonia may vary in different samples of liquor. The analyses of the Samples A and B were made by Dr. Letheby, of C and D by Mr. Wills, and of Nos. 1 and 2 by Mr. Keates.

TABLE 2.

Sample	A	B	C	D
Specific gravity at 60°....	1043.4	1025.3	1027	1044
Ammonia uncombined in oz. avoird. per gallon....	1.16	3.2	1.18	3.14
Ammonia, not recognised by acid, combined in oz. avoird. per gallon.....	4.828	0.6388	5.77	1.37

TABLE 3.

Numbers of Samples	Sp. Gr. at 60°	NH ₃ shown by Test-Acid per Cent.	NH ₃ combined with Sulphuric and other Acids per Cent.	Total Ammonia contained in One Gallon per Cent.
1	1116	1.158	0.278	1.436
2	1060	2.277	3.422	5.699

Calculated into "ounces" of H₂SO₄, the foregoing analyses yield the following results:

TABLE 4.

Sample	A	B	C	D	1	2
Total "Ounce" liquor by <i>distillation</i>	17.24	11.06	20.02	12.98	6.62	26.25
"Ounce" liquor, by <i>acid</i>	3.34	9.22	3.40	9.04	5.34	10.48
"Ounce" liquor, <i>fixed</i> ..	13.90	1.84	16.62	3.94	1.28	15.77
Total Ammonia = 100 Ammonia, <i>fixed</i> , <i>p. cent.</i>	80.5	16.63	83.02	30.3	19.35	60.04

The "ounces" of Nos. 1 and 2 in Table 4 have been calculated by simply multiplying the per centages of ammonia as given by Mr. Keates (Table 3) by 4.61, as per note to Table No. 1, and are very nearly correct, as that gentleman states that No. 1 sample by the acid-test would be "about 5.5 ounces," No. 2 "about 10.5 ounces" by acid, and about "26 ounces" in total.

573. The untrustworthiness of the hydrometer as an indicator of strength in exceptional cases is seen by the comparisons which follow:

	A	B	C	D	1	2
Total "Ounce" liquor by <i>distillation</i>	17.24	11.06	20.02	12.98	6.62	26.25
"Ounce" liquor by <i>Twaddle</i>	17.30	10.12	10.80	17.60	46.42	24.00

574. *To Find Quantity of Sulphate Producing from any Liquor.*—It may be useful to remark that each ounce of acid (H_2SO_4) combines with 0.347 ounce, nearly, of ammonia to form neutral sulphate, $2\text{NH}_3 + \text{H}_2\text{SO}_4 = (\text{NH}_4)_2\text{SO}_4$. Hence, to find the quantity of sulphate producible from any liquor the "ounce" strength of which has been determined by "distillation," multiply the "ounce" strength by 1.347, and by the number of gallons. If the strength of the liquor is stated in *percentage* of ammonia, multiply the total percentage ounces by 4.61, next by 1.347, and finally by the number of gallons. The product will be the total weight in ounces of sulphate. If it is desired to calculate direct in *pounds* per gallon, multiply the "ounce" strength by .841 instead of by 1.347 and move the decimal place one figure to the left. Ex. liquor 9 "ounce," $9 \times .841 = 7.560$, and

moving the decimal place = .7569 pounds of sulphate per gallon.

575. *Sulphuretted Hydrogen and Carbonic Acid in Gas Liquor.*—It may be necessary, in order to check the working of the scrubbers and washers, in extracting the above impurities from the gas, to test for H_2S and CO_2 in gas liquor. The following, among other methods, are in general use, and are due to Mr. Leicester Greville:

576. *H_2S in Gas Liquor (Leicester Greville's Test).*—Prepare a solution of ammoniacal copper sulphate as described in paragraph 482. This is of such a strength that 1 cubic centimetre equals 0.05 grain H_2S . Fill a 25-cubic-centimetre burette with the copper solution. Carefully measure 100 grains of the liquor under test into a white porcelain basin, diluting with a little distilled water and adding a proportion of strong ammonia. Run in the copper solution carefully, stirring vigorously, and noting the first appearance of a slight brown tint. Record how much copper solution was used up to this point and then run in more rapidly, stirring constantly. The solution will remain brown and turbid until the point of neutralisation is reached, when the black copper sulphide will separate in heavy particles, leaving a colourless, supernatant liquid. If too much copper solution has been used a blue tint will appear, in which case a second test must be made; a little experience will prevent this.

577. Each cubic centimetre of copper solution used indicates the presence of 0.05 grain H_2S , but the presence of cyanides in the liquor influences the test and a slight correction must therefor be made. The deduction of the amount of the copper solution which was used *before the brown tint appeared* will, Mr. Greville states, remedy the error.

Thus, suppose 100 grains liquor were taken,
 and 0.8 c.c. of copper solution was used before producing the brown tint,
 and a total of 6.6 c.c. of copper solution was used before the reaction was complete;
 then $6.6 - 0.8 = 5.8$ c.c. copper solution was neutralised by H_2S present in the liquor,
 and $5.8 \times 0.5 = 0.29$ of H_2S per cent.

578. The following figures are given by Mr. Greville as obtained by this test (*Journal Gas Lighting*, June 23, 1896):

Condenser liquor	1.180	per cent.
Scrubber	0.470	"
" check test.....	0.475	"
" 	0.680	"
Condenser	0.410	"
Unnamed	0.107	"
Well liquor	0.607	"
Weak scrubber liquor	0.081	"

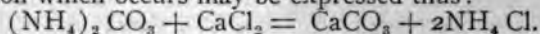
The above figures approximate closely to those obtained by a gravimetric process.

579. *CO₂ in Gas Liquor* (Leicester Greville's test.—For this test the following solutions are required: The ordinary 10 per cent. acid used for gas liquor testing (par. 554 *et sequitur*), and a calcium chloride solution. This is made by dissolving half a pound of ordinary dry calcium chloride in distilled water in a flask, adding carefully some dilute HCl (to correct the faint alkalinity) until there is a neutral reaction; the solution is then made up to half a gallon and filtered. It has a strength of about 9 per cent.

580. Mr. Leicester Greville's instructions are as follows:

The process depends on the fact that, whereas the ordinary 10 per cent. acid is an indicator of all compounds of ammonia in gas liquor capable of being decomposed by its action, the addition to the liquor of an excess of calcium chloride decomposes the ammonium carbonate present, precipitating calcium carbonate, and fixing the ammonia previously in combination with CO_2 as neutral ammonium chloride. The precipitated calcium carbonate

being removed by filtration, the alkalinity of the filtrate is determined with 10 per cent. acid; and the loss of alkalinity is a measure of the proportion of CO_2 present. The reaction which occurs may be expressed thus:



581. The mode of procedure is as follows:

Take, say, 1000 grains measure of the liquor to be tested, pour into a white porcelain basin, and (using methyl orange as an indicator) find how many cubic centimetres of 10 per cent. acid are required for neutralisation. Having noted this, measure 2000 grains of the liquor into a stoppered decigallon measure, and add 2000 grains measure of the calcium chloride solution. Shake vigorously at intervals, and after a brief period the calcium carbonate will settle rapidly down as a dense precipitate. Pour the comparatively clear liquid on to a dry filter paper, filtering into a graduated measure, and when 2000 grains measure have been obtained, pour this amount into a white porcelain basin and determine the alkalinity with 10 per cent. acid as before.

582. The calculation is then simple. Sulphuric and carbonic acids are both what is termed "dibasic"; replacing equivalent proportions of the same alkali in combination. The molecular weight of H_2SO_4 being 98, and that of CO_2 being 44, these figures represent the equivalency of the two acids with regard to the same base. With standard H_2SO_4 of 10 per cent. strength, 1 cubic centimetre of 15.433 grains would contain 1.5433 grains of H_2SO_4 —equal to 0.693 grains of CO_2 . As an example, say that 1000 grains of the raw liquor required 40 cubic centimetres of 10 per cent. acid for neutralisation, and an equal quantity (1000 grains) of the filtered liquor, after treatment with CaCl_2 , required for neutralisation 20 cubic centimetres of test-acid. Then $40 - 20 = 20$ c.c. difference; and $0.693 \times 20 = 13.86$ of CO_2 equal to 1.386 per cent.

583. The following experiments demonstrate the accuracy of the process. The figures, showing determination by

weight in comparison to the volumetric method, were made by washing and weighing the precipitated calcium carbonate, and then calculating the CO_2 :

	CO_2 per cent. Volumetric Process.	CO_2 per cent. Gravimetric Process
Condenser liquor	2.020	1.950
Scrubber "	1.800	1.840
" "	0.664	0.677
" "	0.680	0.690
Unnamed "	0.977	0.951
Surface condenser	0.762	0.763
Well liquor	1.630	1.640
Scrubber	0.069	0.074

The determinations of H_2S and CO_2 can be made easily in 15 minutes, the proportion of H_2S being estimated while the mixture of CaCl_2 and liquor are standing before filtration. With regard to ratio of CO_2 and H_2S per cent. by weight and volume, it may be stated that at 30 inches B, and 60° Fahr.

1 per cent. H_2S = 1.11 cubic feet per gallon.

1 per cent. CO_2 = 0.8256 " "

By multiplying these factors by the weight percentages, the corresponding volumes in cubic feet per gallon may be obtained.

584. *Test for Amount of Ammonia in Sulphate.*—The apparatus for Wills' distillation, Fig. 70, is used for this test. A quantity of the salt is ground and a small portion of this weighed and dissolved, so as to make a known and convenient quantity of solution. A measured portion of this, together with an excess of caustic soda, is placed in flask C, which is heated, the evolved ammonia being arrested in flask G, which contains a known quantity of normal sulphuric acid. This is titrated back with normal caustic soda. The number of cubic centimetres of normal acid used less

the number of cubic centimetres of caustic soda required to neutralise contents of flask *G* after the distillation gives the quantity of normal acid which has been neutralised by the NH_3 present in the sulphate $(\text{NH}_4)_2\text{SO}_4$.

585. *Test for Sulphur in Spent Oxide of Iron.*—The value of spent oxide depends chiefly upon the amount of sulphur it contains. This is tested in the following manner by what is generally known as Stephenson's Test, the method shown in Fig. 71 having been arranged by Mr. Andrew Stephenson. It is based on the fact that free sulphur is dissolved by bisulphide of carbon, and if this is evaporated off the sulphur is left behind and can then be weighed.

586. Weigh 100 grains of spent oxide, dry at 212° Fahr., and weigh to ascertain moisture; put the dried material in test-tube *A*, which is provided at the bottom with a filter of cotton wool. Fit the filter in the test-tube with care. If too tight, it will prevent filtration; if too loose, it will permit some of the oxide to pass through.

587. Bisulphide of carbon is then blown from the holder, *B*, into the test-tube, *A*, on top of the spent oxide. It percolates the mass gradually and dissolves out the sulphur, the solution finding its way by gravitation into the flask, *C*, which is placed in a water-bath. Cover the bisulphide in holder, *B*, with water.

588. The Bunsen's burner is then lighted, and the application of heat soon vaporises the bisulphide of carbon from the flask, *C*. The vapour finds its way through the connecting tube into the condenser, and is recovered in the receiver, *D*, under water, ready for further use. The sulphur is left in the flask, *C*, (the weight of which has been previously noted), and when all the bisulphide of carbon is driven off the quantity of sulphur may be ascertained.

589. Three or four times the bulk of the oxide will be about the proportion of bisulphide of carbon necessary to

dissolve out all the sulphur. When the sulphur is dissolved out the flask, C, is placed in water oven to drive off the last remaining traces of CS_2 , being weighed at intervals until

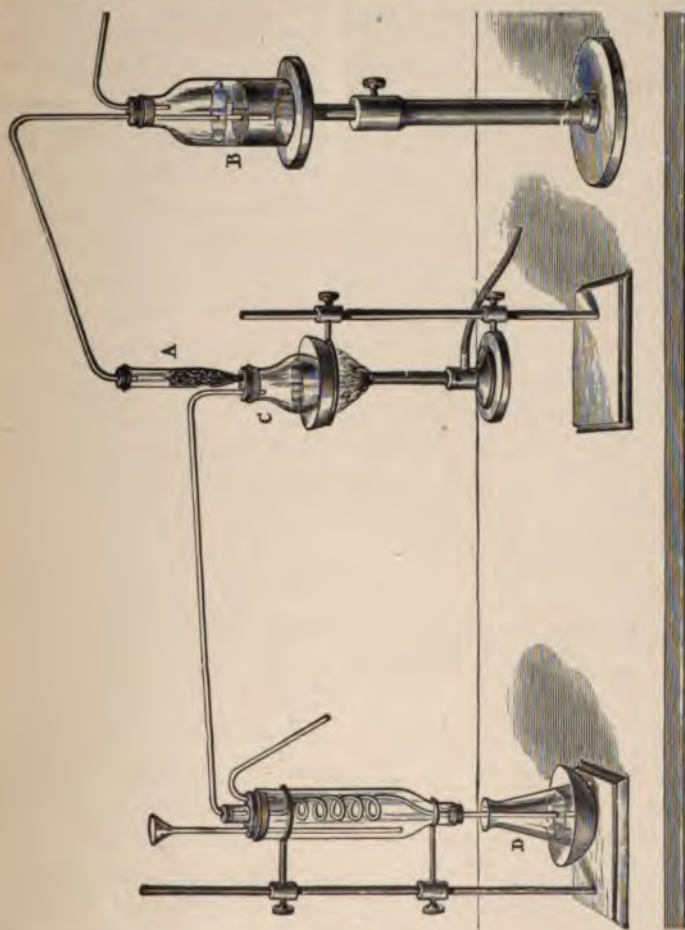


FIG. 71.—STEPHENSON'S APPARATUS FOR TESTING SULPHUR IN SPENT OXIDE.

constant weight of flask and sulphur, minus weight of empty flask, gives weight of sulphur. It must always be borne in mind that bisulphide of carbon is very inflammable,

and in the gaseous state, when mixed with air in certain proportions, it is explosive. It is best to melt the sulphur in the flask before weighing, to drive off all bisulphide of carbon.

590. *The sulphur in spent Weldon mud* is estimated as in oxide, as above.

591. *Tar.* For the assay of coal-tar and the determination of its many products the reader is referred to the standard works on the subject. It will be sufficient to state here that the commercial value of coal-tar depends upon the approximate amounts of: (1) Ammoniacal liquor; (2) light oils, from which are produced benzene, naphtha, etc.; (3) middle, or creosote, oils, from which are produced carbolic acid, naphthalene, etc.; (4) anthracene oils; (5) pitch; while its specific gravity should be known.

592. *The distillation* is carried out in the usual manner in the apparatus shown in Fig. 72. A measured quantity,

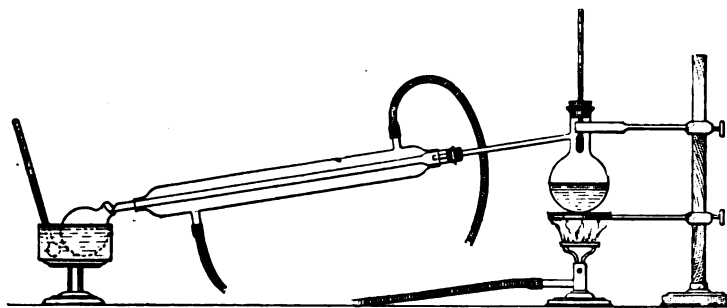


FIG. 72.—APPARATUS FOR TAR DISTILLATION.

say, 1 litre of tar, is placed in a distillation flask, of which the weight is known, the flask being of sufficient capacity that it is only about two-thirds full. The flask is then weighed and the difference between this and the previous weighing (in grammes) gives a figure which, divided by 1000, equals the specific gravity of the sample, as compared with water.

The flask is mounted and connected, as shown, with a Liebig condenser, through which a stream of water can be circulated; the condenser conducts the products of the distillation into the receiver, which can be surrounded with water. The distillation is conducted until pitch only remains, and the table below gives the details to be observed during the test:

593.

Products of Distillation	Temperature at which Distilled Over	Means of Distinguishing Products and End of Fraction	Condition of Condenser	Condition of Receiver
1. *Ammoniacal liquor	340° F.	Distillation becomes heavier than water and sinks beyond 340° F.	Surrounded by running stream of cold water	Surrounded by cold water
2. *Light oils—benzol, naphtha, etc.	340° F.			
3. Creosote oils—carbolic acid naphthalene	340° F. to 420° F.	Distillation becomes yellow	Surrounded by hot water and if found necessary heated by burner	Surrounded by warm water at end of distillation
4. Anthracene oils	420° F. to 685° F.	Oil ceases to come over and residue fumes	Condenser replaced by wider one surrounded by hot water	Surrounded by hot water
5. Pitch—residue				

*The above products come over together, but separate out by gravity, with use of separating funnel.

It will be observed that it is necessary to read to a high temperature. A thermometer with nitrogen bulb can be used for this purpose. An addition of the weights of the various products should equal about 94 per cent. of the total amount of tar heated, the remainder being loss on distillation.

594. The following tables are percentages by weight of distillations made of five different samples of tar:

Test No.	1	2	3	4	5
Spec. gravity of tar	1.086	1.102	1.140	1.154	1.206
Ammoniacal liquor	1.20	1.03	1.04	1.05	0.383
Light oils.....	19.67	16.51	8.2	6.04	1.562
Creosote oils.....	26.45	25.83	27.29	27.33	19.440
Anthracene oils...	20.32	15.57	18.13	13.77	12.280
Pitch.....	28.89	36.80	41.80	47.67	64.080

[NOTE.—Pars. 595-619 are left blank to facilitate additions in a future edition.]

CHAPTER X.

TECHNICAL GAS ANALYSIS.

620. The complete analysis of a complex gas, such as coal-gas, is an operation requiring expensive apparatus, a considerable amount of manipulative skill, and a great deal of time. There are many works devoted to the subject, and it is only proposed here to give a guide to the use of apparatus as is ordinarily found on a gas works, and

(1) To deal shortly with the general principles governing the measurement of volume of gas.

(2) To mention and describe the method of preparing the reagents required in a technical gas analysis.

(3) To describe the method of making such an analysis of illuminating gas, (a) by Elliott's apparatus, (b) by Hempel's apparatus.

(4) To describe the method of making such an analysis of furnace gas, (a) by Orsat Muencke's apparatus, (b) by Bunte's apparatus.

It should be stated that an exact analysis of gas is made by means of what is termed a *constant volume* apparatus, in which the tension of the gas when expanded to the same volume (after having been successively treated with reagents) is measured. For ordinary purposes, however, and in the methods described below, the analysis is made by means of what is termed a *constant pressure* apparatus, in which the volume of the gas when subjected to the same pressure (after having been successively treated with reagents) is measured.

The Corrections for Volume.

621. When a gas is measured volumetrically, as it is in an analysis, it is expressed in *percentage of volume*, and seeing that the volume of a gas changes with variations of atmospheric pressure, temperature, and tension, due to the absorption of aqueous vapour, it is necessary, in order to obtain a standard of comparison, to reduce all volumes as measured, to the volume which the measured quantity of gas would occupy with the *barometer at 760 millimetres, the thermometer at 0° Centigrade, and in a dry state.*

622. The following are the formulæ which govern the reduction of a measured volume of gas to a normal state:

(1) *Atmospheric pressure.* According to Boyle's law, the volume of a gas is in inverse ratio to the pressure to which it is subjected.

Hence if:

V_o = The Volume of gas at 760 mm. (normal) pressure

v = The observed or measured volume of the gas

p = The observed state of barometer in mm. at the time the volume was measured

Then:

$$V_o = \frac{pv}{760}$$

Example: Let 152 c.c. of gas be measured at 770 mm. pressure. Its volume at 760 mm. (normal) pressure will be

$$\frac{152 \times 770}{760} = 154 \text{ c.c.}$$

(2) *Temperature.* The expansion by heat of a gas is $\frac{1}{273}$ (0.0003665) of its volume at 0° C. for each deg. C. of increased temperature.

Hence, if:

V_o = The volume of the gas at 0°C . (normal) temperature.

v = The observed or measured volume of the gas at t where

t = The degree (Centigrade) of temperature at the time of observation. Then

$$V_o = v \frac{273}{273 + t}, \text{ or, } \frac{v \times 273}{273 + t}$$

Example:

Let 566 c.c. of gas be measured at 10°C . Its volume at 0°C . (normal) temperature will be

$$\frac{566 \times 273}{273 + 10} = 546 \text{ c.c.}$$

(3) *State of Moisture*.—When a gas is saturated with moisture by contact with water it always (under the same conditions of temperature and pressure) contains the same amount of moisture. This moisture is the water itself transformed into a gaseous state, and it exerts a certain pressure which increases with the temperature (because the formation of the moisture increases with the temperature), affects the volume, and is termed “tension of aqueous vapour.”

This “tension of aqueous vapour” has been determined experimentally for each degree of temperature, and is expressed in millimetres of mercury. It should be deducted from the barometric pressure, and can be found by reference to the table prepared by Regnault.

If, therefore, w is the tension of aqueous vapour in a volume of gas measured under an atmospheric pressure, p , the true pressure on the gas is $(p - w)$.

From the preceding formulæ it will be seen that a correction for temperature, pressure and state of moisture can be made by the following formula, and the gas reduced to its volume under normal conditions of barometer (760 mm.) thermometer (0°C .), and in a dry state.

Let

v = Observed or measured volume of gas

t = Temperature at which measurement was made

p = Atmospheric pressure at which measurement was made

w = The tension of aqueous vapour at t°

Then

$$V_o = \frac{v \times 273 \times (p - w)}{760 (273 + t)}$$

or, if the gas is dry and it is therefore not necessary to correct for tension of aqueous vapour,

$$V_o = \frac{v \times 273 \times p}{760 (273 + t)}$$

623. It is obvious that a quick approximate analysis can be made without correction to the normal state; the correctness of such analyses is facilitated if they are made under constant temperature and pressure. If an analysis is made in a room the temperature of which is kept even and with the reagents and water at the same temperature as the room, there is no reason why, if the analysis is conducted quickly, the various gases should not be measured at the same temperature and atmospheric pressure, and correction thus avoided. Some of the apparatus which will be described below are primarily intended to be used with water as the confining liquid. This induces a certain amount of error, owing to the absorption by the water of certain of the constituents it is sought to analyse. The error in the analysis of coal-gas depends to a large extent upon the manipulative skill of the operator. The error is lessened if the water is saturated with the gas it is desired to analyse, and is entirely done away with (saving manipulation) if an apparatus is used in which the gases are collected over mercury.

The Reagents Required.

624. The following are the reagents required for the analysis of the illuminating and furnace gases in the manner hereafter described.

Alcohol is used for the determination of hydrocarbon

vapours (benzene). Ordinary absolute alcohol is used, and the gas, after being subjected to its action, must be agitated with water previously saturated with gas, so as to remove the alcohol vapours.

625. *Caustic potash or potassium hydroxide (KHO)* for the absorption of carbon dioxide (CO_2) is used in solution consisting of one part commercial caustic potash (not purified by alcohol) and two parts of water, say, half a pound of stick potash in a pint of distilled water. In addition to being the absorbent for CO_2 it is also used for removing the vapours after the gas has been treated with either fuming sulphuric acid or bromine water, and for estimating the amount of CO_2 formed after the explosion for estimation of marsh gas.

626. *Potassium pyrogallate* for the absorption of oxygen (O) is a potash solution of pyrogallic acid made by mixing as required pyrogallic acid with caustic potash solution. It has great affinity for oxygen and, therefore, is difficult to keep. It should be made as required. Take, say, 5 grammes of the pyrogallic acid, mix with three times its weight of water (distilled), and follow it in the absorption pipette or other vessel by about eight times its volume of strong solution of caustic potash (not purified with alcohol).

627. *Bromine* for the absorption of the hydrocarbons (other than methane) in illuminating gas should be used as an almost fully saturated solution. After the absorption of the hydrocarbons, and before measurement of residual volume, the bromine vapour must be removed by the KHO solution. Bromine in a solution of bromide of potassium can also be used.

628. *Fuming sulphuric acid (Nordhausen)* for the absorption of the hydrocarbons (other than methane) in illuminating gas is used alternatively to bromine for this purpose. When used the absorption vessel should be filled with

glass beads, and after the absorption of the hydrocarbons and before measurement of residual volume the vapours must be removed by the KHO solution.

629. *Cuprous chloride solution* for the absorption of carbon monoxide (CO) is used either as an ammoniacal or hydrochloric acid solution. The action of the former is sharper, but as the latter is less troublesome to prepare, it is mostly used in technical analysis. Its action in either form is not very certain, owing to the difficulty of absorbing the last traces of the CO.

The cuprous chloride from which the solutions are made is prepared by first making cupric chloride (10 grammes of oxide of copper in about 150 cubic centimetres concentrated HCl), and then placing this in a flask filled with copper wire or gauze. This reduces the cupric to cuprous chloride and becomes, when the change is completed, colourless. This is then placed in distilled water in a large vessel and the cuprous chloride is precipitated and ready for forming either the ammoniacal or hydrochloric acid solutions.

The ammoniacal solution is made by putting about 20 grammes of precipitated cuprous chloride into a measuring flask of 250 or 300 cubic centimetres' capacity and containing about 200 cubic centimetres of distilled water. Ammonia is led into the solution by boiling off in another flask a strong solution and leading the outlet tube into the flask containing the cuprous chloride. Stop the action when the solution assumes a pale-blue colour, and make up to 250 cubic centimetres with distilled water. While the ammonia is being evolved avoid the presence of air in the cuprous chloride flask by using a two-holed stopper, leading the ammonia tube through one and through the other a bent tube, dipping slightly into mercury. The solution should then be kept free from air, and must not be diluted.

The hydrochloric acid solution of cuprous chloride is prepared by placing precipitated cuprous chloride in a stoppered bottle and pouring into it concentrated hydrochloric acid (1.124 specific gravity), in the proportion of 50 grammes of the former to 250 cubic centimetres of the latter. The bottle is constantly shaken while this is being done and a spiral of copper (ordinary copper turning) is placed in the bottle, so as to reach from the bottom to the top. The stopper should be a rubber bung or well-greased ground glass. The solution will at first be dark, but afterwards completely colourless and clear.

630. *Oxygen and Hydrogen*.—These are required for explosions, and are prepared in the usual manner. Care should be taken that they are pure.

Phosphorus may be used for estimation of oxygen. It is used in the simple pipette for solids (Fig. 78), and is prepared in sticks.

The Elliott Gas Analysis Apparatus.

631. This apparatus was designed by Dr. Arthur H. Elliott for the rapid analysis of coal gas or flue gases. In it water is used as the containing liquid, and to obviate the error due to absorption that would arise through the constant washing of the gas to get rid of each reagent, the gas is removed from the absorbing vessel and measured in another vessel, without washing.

632. The apparatus is shown in Fig. 73. *A* is the laboratory tube, of about 125 cubic centimetres' capacity; *B* is the measuring tube, which holds 100 cubic centimetres from the point *D*, or zero, to the mark on the capillary tube, *C*, and is carefully graduated into 0.1 cubic centimetre. The cock, *I*, is a three-way tap, and has a delivery through its stem. The tubes, *A* and *B* are connected as shown to two bottles,

L and *K*, each holding about 1 pint. The tubes, *A* and *B*, are connected to one another by capillary tubes of small bore. *M* is a spherical funnel of about 60 cubic centimetres' capacity. *G* and *F* are stop-cocks, the end of the latter being ground to fit the funnel *M*. A piece of rubber tube *E* joins the capillaries, which are ground square to fit closely.

633. In commencing an analysis the stem-exit of the

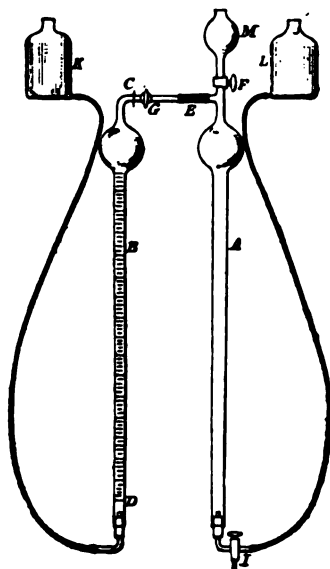


FIG. 73.—ELLIOTT'S GAS ANALYSIS APPARATUS.

three-way cock, *I*, is closed by turning it so that there is a free way between the bottle, *L*, and the laboratory tube, *A*; the cocks, *F* and *G*, are opened and water is allowed to fill the apparatus from the two bottles. When the water rises in the funnel, *M*, and all air bubbles have been expelled, cocks *F* and *G* are closed, *M* is removed and the gas delivery tube attached in its place. The bottle, *L*, is lowered slowly and the cock *F* simultaneously opened, so that the tube, *A*,

is nearly filled with gas; the cock *F* is then closed. The gas delivery tube is removed, the funnel, *M*, replaced, the bottle, *L*, raised, the cock *G* opened and the bottle, *K*, lowered, and the gas is thus transferred to the measuring tube, *B*. The bottle, *K*, is now adjusted so that the level of the water in it is the same height as the zero mark, *D*, on the measuring tube. By means of the bottle, *L*, the gas is adjusted to this zero mark, *D*, and the stop-cock *G* is closed. The final adjustment is made after waiting a few minutes for the gas to attain the same temperature as the apparatus. The measuring tube will now contain 100 cubic centimetres of gas. The atmospheric temperature and pressure should be recorded.

634. The excess of gas in *A* is expelled by opening stop-cock *F* and raising bottle *L*. The gas remaining in the capillary tube between *C* and the vertical part is disregarded, as its volume is very small. It may, however, be ascertained and an allowance made.

635. The gas being measured, it is now transferred by raising the bottle *K*, and lowering *L* into the tube *A*, and the cock *G* closed. The reagents are added by placing them in the funnel *M*, and allowing them to flow down the sides of the tube *A* slowly, care being taken not to unseal the vertical tube in the funnel by letting the fluids run below this level. A seal of about three-quarters of an inch should always be kept and the reagents not allowed to run below this. The stop-cock *F* is so adjusted that the reagents spread over the sides of the tube *A*, and thus expose the gas to a large absorbing surface. During this process the water level in *A* is brought as low as possible and the cock *I* closed.

636. Having treated the gas with the reagent, it is transferred by means of the bottles to tube *B*, and its volume measured and noted. Each successive diminution in volume will represent the amount absorbed of the constituent gas, and

such volume will require no correction if the temperature and pressure have remained constant. If any variation has taken place correction is made as described in paragraph 622. If the chemical gets into the horizontal capillary tube the passage of a little water from the bottle *K* will remove it before transferring the gas. The measurement is made (subject to correction as above) by adjusting by means of the bottle *L* the fluid of *A* to the mark *C* on the horizontal tube, closing the stop-cock and then raising or lowering the bottle *K* until the level of its fluid and that of the tube *B* are the same, and letting the water in *B* settle down from the sides of the tube before reading.

637. The absorption tube *A* now requires cleansing of the absorbent used before the gas is again transferred. This is done by turning the cock *I*, so that there is a free downward passage and letting water run through the tube *A* from the funnel *M*. When the tube is clean the cock *I* is turned so as to reconnect the bottle *L* with the tube, the water is forced into it by raising the bottle *L*, and the whole is ready to receive the gas again for treatment with the reagent. The analysis is made as follows:

638. *CO*₂.—The KHO is run in slowly, about ten minutes being required for the absorption.

Oxygen (O).—The solution of pyrogalllic acid followed by an excess of caustic potash (or if freshly prepared, the potassium pyrogallate) is slowly run into the tube, the absorption taking about twenty minutes.

Hydrocarbons.—Bromine water is run in. It is best effected by adding a few drops from a pipette to water in the funnel, and the tube should be filled with vapour. Care must be taken not to add too much, otherwise the vapour will cause a pressure which will drive out the gas upward through the funnel. The vapour must be absorbed by pass-

ing in some of the KHO before transferring the residual gas to the measuring tube.

Carbon monoxide (CO).—Cuprous chloride (HCl) solution is now run in, the absorption taking about half an hour. It is followed by a *weak* solution of KHO to absorb acid vapours, and the gas is then transferred to *B* and measured.

639. By the above means an illuminating gas can be analysed, leaving a mixture of marsh gas, hydrogen and nitrogen. These can be determined by the explosion burette described below. If a furnace gas has been examined the CO₂, O and CO could be ascertained as above, leaving out the bromine absorption. It is advisable to surround the tube *B* by a water jacket, so as to secure a constant temperature in measuring the volumes.

640. The explosion burette is shown in Fig. 74. It consists of a burette *P* of heavy glass graduated in tenths of cubic centimetre, and holding 100 cubic centimetres to within two inches of the lateral tube *R*; the upper end is closed by stop-cock *Q*, and is ground to receive a funnel *U*, similarly to top of *B*. (Fig. 73). The stop-cock *Q* is the zero point, and the 100 cubic centimetre mark is near the lateral tube *R*. In the upper end of tube are fused two platinum wires. At the lower end of burette is fitted a cock *S*, connecting by rubber tube to aspirator bottle *T*. Care should be taken that the opening at *S* and the tubulure of bottle are not smaller than the bore of the rubber tube, as any contraction would prevent the cushioning of the explosion. The burette should be held in a spring clamp.

641. The burette is connected by means of the capillary with ground end *X* (replacing funnel *U*) to the measuring tube *B* (Fig. 73), being joined by rubber tube at *E* (Fig. 73). Care must be taken not to introduce air by filling the capillaries with water. An improved form of the apparatus which facilitates the manipulation is shown in Fig. 75. The

explosion burette is filled with water from *T*, and about 20 cubic centimetres of the residual gas from *B* passed into *i* and the cock *Q* closed. The gas is measured by lowering bottle *T* until the water level in it and in the explosion burette are equal, and then about 20 cubic centimetres of air

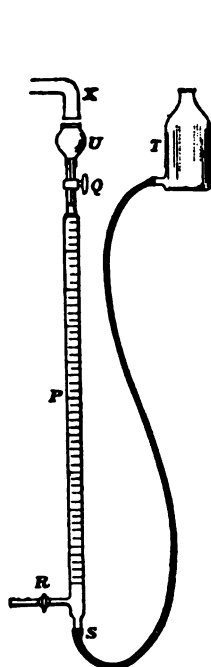


FIG. 74.
EXPLOSION BURETTE
(ELLIOTT'S APPARATUS).

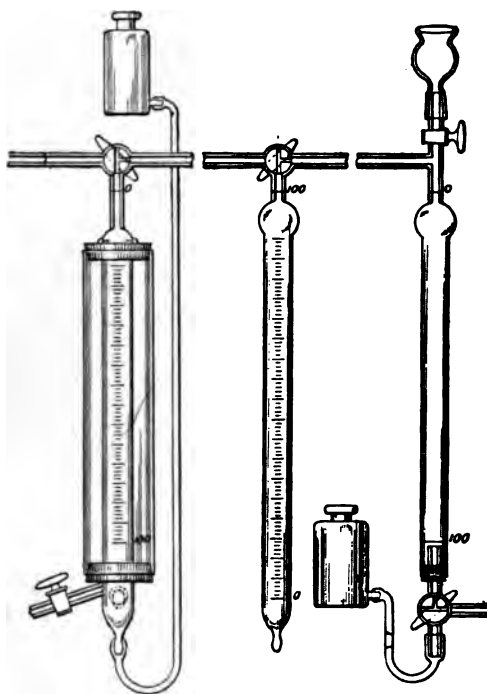
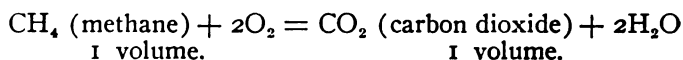


FIG. 75.
ELLIOTT'S APPARATUS (IMPROVED FORM).

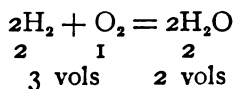
and 40 cubic centimetres of oxygen are introduced through *R* and the total volume carefully measured, the temperature and atmospheric pressure being, as before, noted. The burette can be removed from its stand, and by a few movements the gas, air and oxygen are mixed. A spark from an induction coil is now applied, the aspirator being below the level of *S* (which is opened), in order to expand the mixture

during explosion. A sharp click indicates the explosion, and the tube is allowed to stand, so that the gas may cool before the contraction is read. After this is ascertained the funnel is replaced and caustic potash is run in to absorb the CO_2 , when the residual volume is again read, this giving the amount of CO_2 absorbed.

642. The contraction on explosion is due to the fact that upon explosion the hydrogen of the gas combines with oxygen and forms water, while the carbon of the methane combines with oxygen and forms carbon dioxide. Now, the volume of the CO_2 formed equals the volume of the methane, as will be seen from the following :



Therefore, the amount of methane is equal to the amount of carbon dioxide absorbed by the caustic potash. The contraction due to CO_2 is equal, however, to twice the volume of methane present, because this latter in burning combines with twice its volume of oxygen (as is seen above), and the contraction is equal to the oxygen consumed, or to twice the volume of methane present. The amount of hydrogen present equals two-thirds the total contraction less that due to methane, because 3 volumes of H and O only yield 2 volumes of water; thus,



The contraction being due, as stated before, to combustion of methane forming CO_2 and of hydrogen forming H_2O , the amount of hydrogen can be ascertained by taking two-thirds of the remainder of the contraction. The difference is estimated as nitrogen. It may contain, however, an excess

of oxygen, and this can be ascertained by absorption with potassium pyrogallate. (See also pars. 670 *et seq.*)

643. The following makes the contraction calculations clear:

Let A = total contraction and B the CO₂ found
 then B = methane present
 then contraction due to methane = 2B
 $\therefore$ methane = CO₂ (as found by absorption)
 $\therefore$ hydrogen = $\frac{2}{3}[A - 2(\text{CO}_2 \text{ or methane})]$

644. *Hempel's apparatus* is made in various forms. It consists essentially of (1) a measuring burette; (2) a tube or bottle connected to the measuring burette and holding and containing liquid, such as water or mercury; (3) a series of absorption pipettes, in which the gas is brought into contact with the various reagents. A full description of the apparatus will be found in "Methods of Gas Analyses," an English translation of Dr. Hempel's book by L. M. Dennis. Most of the modifications have been in the direction of the measuring burette, and the one described in pars. 82 *et sequitur* is a recent modification by J. G. Taplay (Gas Light & Coke Co). The manipulation of this form is also described, and from this explanation the method of using the ordinary Hempel burette and pipettes described in the following paragraphs will be obvious:

645. The Hempel burette for use with mercury is shown in Fig. 76. It consists of a glass tube surmounted by a two-way cock and having a capacity of over 100 cubic centimetres. The graduations are to 100 cubic centimetres divided into fifths, measured from below the stop-cock, and with the figures running up and down. The stop-cock enables communication to be made from the burette to the tube connecting to the various pipettes, or from the burette to the

correction tube. This correction tube contains air in a moist state, and its connection to the burette is intercepted by a manometer tube filled with mercury. The utility of this correction tube will be presently explained. The burette is surrounded by a glass tube containing water, so as to facilitate the measurement of the gas at a constant temperature. At the bottom of the burette a vessel on stand containing mercury is connected by means of a rubber tube with glass stop-cock. By raising or lowering this mercury vessel,

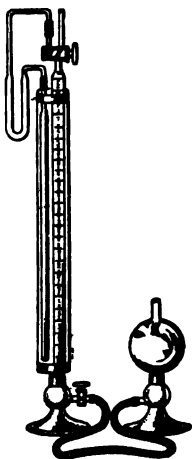


FIG. 76.—HEMPEL BURETTE.

and with the stop-cock at top of burette open, gas can be drawn in or expelled, and by this means the gas is first brought into the burette and successively passed into and drawn back from the various pipettes to be measured before and after the different absorptions. It is obvious, however, that some means must be provided of always measuring the gas at the same pressure. In an apparatus in which water is used (as Elliott's, previously described) this is done by bringing the water in the burette and the bottle to the same level. Here, however, mercury is used, and the mere



FIG. 77.—SIMPLE PIPETTE.



FIG. 78.—SIMPLE PIPETTE (SOLIDS).



FIG. 79.—DOUBLE PIPETTE.



FIG. 80.—SIMPLE PIPETTE
(FUMING ACID).

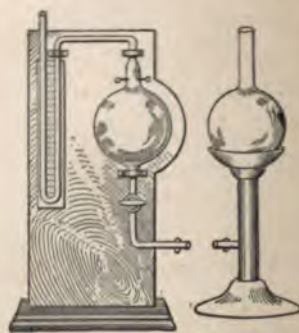


FIG. 81.—ALCOHOL, MERCURY OR
EXPLOSION PIPETTE.

observation of the levels would not be sufficient, owing to the greater weight of mercury. The correction tube with manometer is therefore provided. It has been stated that the air in correction tube is at atmospheric pressure. If, therefore, the stop-cock from burette is opened to this tube, the mercury bottle can be raised or lowered, compressing or distending the gas until a pressure equal to that in the correction tube, (*i. e.*, atmospheric pressure) is exerted on the burette side of the manometer; in other words, until the level of the liquid in the two limbs of this manometer is equal. When this equality of level is obtained the gas in the burette is also at atmospheric pressure, when the cock at bottom of burette is shut off and the volume of gas read.

646. There are various forms of pipettes, which are modified to suit different absorbents. They are:

- (1) The simple pipette (Fig. 77).
- (2) The simple pipette for solids (Fig. 78).
- (3) The double pipette for reagents which require isolation from the air (Fig. 79).
- (4) The simple pipette with 3 bulbs for use with fuming acid (Fig. 80).
- (5) The mercury pipette used for alcohol absorptions, and also provided with terminals for explosions (Fig. 81).

647. The simple pipette is shown in Fig. 77. It consists of two large bulbs joined together and a thick-walled capillary tube. The larger bulb has a capacity of about 150 cubic centimetres, the smaller about 100 cubic centimetres, and the capillary tube has a backing of opal glass to enable the level of liquid to be easily read. The end of the capillary tube has a small piece of rubber tube wired to it. The whole pipette is mounted on a wooden stand for protection and convenience.

648. The solid pipette is shown in Fig. 78. The difference in form is to enable a solid reagent to be introduced.

649. The double pipette is shown in Fig. 79. It is used where a reagent is employed which is acted upon by oxygen, such as potassium pyrogallate, cuprous chloride, etc., the two end bulbs having each a capacity of about 100 cubic centimetres and being filled with water.

650. The three-bulb simple pipette, Fig. 80, is for use with fuming acid, the upper bulb containing beads and thus offering a large surface covered with the reagent to the gas.

651. The explosion or mercury pipette, Fig. 81, is used for explosions, and is provided with platinum terminals for connection to a battery when an explosion is to be made, and also with a cock at the lower extremity of the bulb, so that mercury can be passed in and contained when an absorption with alcohol is required. The pipettes used in the analysis described below are the same as above, but are modified in two particulars, viz., the end of the capillary tube is not provided with rubber tube, but is in ground-plug form; and, secondly, all the pipettes have a glass cock between the capillary tube and the absorbing bulb. The reason for this will be made obvious.

652. Taplay's modifications of Hempel's apparatus are as follows, and are designed *inter alia* for rendering simple the manipulation of the burette and pipettes without introducing air, a difficult matter in the ordinary forms. The water-jacket is made of larger diameter than that which has been usually provided with this instrument; thus, the burette and the correction tube are surrounded by a larger volume of water, and the chances of the alteration of temperature are lessened. The extremities of the manometer or pressure gauge are capillary; the levels of the mercury in the two limbs can be more easily determined. The connection between the burette and the absorption pipette is made by a capillary tube, according to Hempel, but as the air cannot be satisfactorily displaced from this simple con-

nection, a modification is introduced (see Fig. 82) which disposes of this difficulty. Instead of a rubber connection between the capillary from burette and that forming part of the pipette, a ground-glass joint is made, thus offering nothing for the reagent to attack, and no trouble from inclosed air when connecting up. It is better to have a tap at the upper part of the larger bulb of the absorption pipette; when the gas is enclosed within this bulb the tap is closed, the pipette disconnected and the gas shaken up with the reagent. This applies both to the pipette in globular form and to the pipette used for solid reagents. There should also be a tap at the upper part of the explosion pipette, as well as at the bottom of same; the upper tap should be so placed that between it and the platinum wires there is a little mercury to act as a cushion during the explosion. J. T. Sheard has found this latter of advantage (see *Journal of Gas Lighting*, Vol. LXXII, p. 42). As the pressure of the mercury (which is employed as the confining agent) on the taps at various parts of the apparatus is considerable, owing to its weight, each of these taps has a V-thread cut at the smaller end of the plug, and carrying two milled-edge vulcanite nuts to prevent the plug from loosening and allowing the mercury to find an exit. A thermometer is suspended in the water-jacket, so that the operator may note any alteration of the temperature.

653. Fig. 82 shows the apparatus connected to a simple pipette. The burette *A* is graduated to 100 cubic centimetres, and is closed at the top by a Greiner-Friedrichs stop-cock *E*, which opens into the two capillary tubes *D''* and *F*. The burette is connected by two short pieces of rubber tubing with the manometer, or pressure-gauge *D* and the Pettersson correction tube *B*, which latter is a plain glass tube closed at the bottom. Both the burette and the correction tube stand in a wide glass cylinder *C*, filled with water.

This cylinder is open at the top, and is closed at the bottom by a single-bore rubber stopper or a good and well-fitting cork. The U-shaped part of the manometer tube *D* is

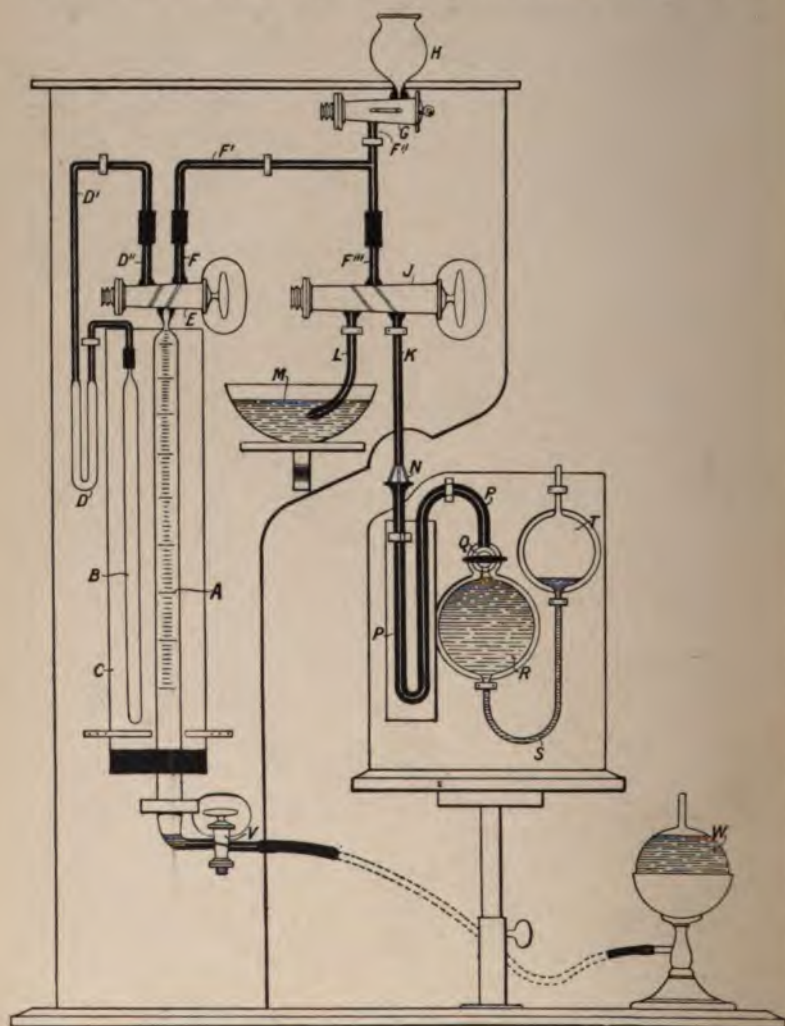


FIG. 82.—TAPLAY'S IMPROVED HEMPEL'S APPARATUS.

about 6 millimetres wide, each limb being reduced to a capillary tube; mercury is used as the confining agent, both in the manometer and in the burette. As the gases are generally measured in a moist condition, a drop of water is introduced into the correction tube *B*, before connecting to the manometer. The capillary tube *F* is joined by a piece of rubber tubing to another capillary tube *F' F''*, and surmounted by a stop-cock *G*, carrying a cup *H*. This piece of capillary is further connected by rubber tubing to stop-cock *J*, by the capillary *F'''*. The stop-cock *J* is also a "Greiner-Friedrichs" pattern, and opens into two other capillary tubes, *L* and *K*. The tube *L* projects into a small basin holding a little mercury, the basin resting on a shelf fixed to the side of the wooden support which carries the burette, etc.; the tube *K* terminates in the socket portion of the ground-glass joint *N*. The tubes *F'' F'''* and *K* may be washed out after each absorption with a little water which is poured in cup *H*. The capillary tubes of the absorption pipettes terminate in cone-shaped ends ground to make a joint with the socket end of the tube *K*. The joint at *N* may be made with a piece of rubber tubing, if preferred, but as the reagent is contained in the capillary tubes *K* and *P*, it is advisable to employ a ground-glass joint, to which a little vaseline may be applied. The ends of the capillary tubes *D D' F F' F''* and *F'''* should be ground flat, so as to make a good face joint and so prevent small quantities of air from lodging, which air ought to be displaced by the mercury employed for that purpose. The lower end of the burette *A* is connected by rubber tubing to the stop-cock *V*, and the level bulb or mercury reservoir *W*, which is carried on a wooden foot. The rubber tubing should be stout enough to resist the pressure of the mercury without bursting, and it is advisable to secure it to the apparatus by binding with copper wire.

654. Before using the apparatus for an analysis the capacity of the space between the surface of the mercury in capillary tube *D'* of the manometer and the bottom of the passage in stop-cock *E*, which connects capillary tube *D''* with the burette *A* must be determined once for all. This is done by drawing some air into the burette and then bringing the stop-cock *E* into the position shown on alternative sketch, so that the burette communicates with the manometer. By raising or lowering (as the case may be) the level-bulb *W*, the inclosed air can be brought to the pressure of the air in the correction tube *B*. This is accomplished when the mercury stands at the same height in both limbs of the manometer *D*. The stop-cock *V* is now closed, and the volume of air in the burette is noted. Upon again opening stop-cock *V*, and lowering the level-bulb *W*, the mercury in the manometer tube *D* is carefully drawn over until it reaches the bottom of the passage in stop-cock *E*, which latter is then closed by turning through 90° , the levels of the mercury in the burette and the level-bulb are made to coincide, the stop-cock *V* again closed and another reading of the volume of air in the burette taken. The difference of the two readings gives the capacity of the capillary passage between the surface of the mercury in the tube *D'* and the extreme upper end of the burette. The air inclosed in correction tube *B* is brought to the same pressure as the surrounding atmosphere by disconnecting the tube *B* and the manometer tube at the rubber joint.

655. This capacity constant having been determined, the general manipulation is as follows: Turn the cock *E* so that the burette communicates with capillary tube *F* and open the cock *G*. Now raise the level-bulb and allow about 5 cubic centimetres of mercury to flow into the burette by opening cock *V*. Now close cocks *V* and *G*; connect the absorption pipette to the capillary tube *K* at the ground-

glass joint, *N*. Open cock *Q* on pipette, turn the cock *J* so that the capillary tube *K* communicates with *F'''*, again open cock *V* and lower the level-bulb; the mercury in flowing out of the burette will draw the reagent out of the pipette into the capillary tubes *P* and *K*. When the reagent has reached the top of the passage in the cock *J*, the latter is turned through 180° , making communication between capillary tubes *F'''* and *L*. The level-bulb is again raised, whereupon the mercury will flow into the burette and capillary tubes, thus displacing all the air. A little mercury is poured into the cup *H*, the cock *G* opened for a few seconds and then closed again; the mercury will drive the air out of the tube *F''*. When the air has been driven out of the burette and capillary tubes by way of the tube *L*, and the end of this tube becomes sealed by the mercury which flows into the basin *M*, we may proceed to fill the burette with the gas which is to be analysed.

656. Connect the gas-supply to capillary tube *L*, while under the surface of the mercury in the basin *M*, with a piece of rubber tubing; now lower the level-bulb and the mercury in the capillary tubes and the burette will be drawn away, followed by the gas. When sufficient of the gas has entered the burette, the rubber tubing is slipped off the capillary tube *L* the mercury in the basin *M* is then drawn through the capillary tubes, completely displacing all the gas from the tubes mentioned. As soon as the mercury is seen to drop into the burette from the cock *E*, this latter cock and cock *V* are closed by turning each through 90° .

657. The gas in the burette *A* is now measured at atmospheric pressure; to do this raise the level-bulb and open cocks *V* and *E*, so that the latter makes communication between the burette and the manometer tube *D*, and when the mercury in both limbs of the manometer is at the same level, the stop-cock *V* is closed and a reading of the volume of gas

in the burette is taken. The true volume is equal to that read off plus the correction-constant. After measuring, lower the level-bulb, open the cock *V* and draw the gas out of the manometer tube back into the burette, after which close the stop-cock *E*.

658. The gas has now to be passed into the absorption pipette *R*; turn the cock *E* so that the burette communicates with the capillary tube *F* (cock *G* is, of course, closed); and cock *J* being turned so that capillary tubes *F'''* and *L* are open to each other, carefully raise the level-bulb, *W*, and allow the mercury contained in the tubes *F F' F'''* to be slowly discharged into the basin, *M*. As soon as the mercury has been discharged from the capillary tube *F'''*, the cock *J* is turned through 180° , making communication between the tubes *F'''* and *K*, the cock *Q* is opened and the gas (which has, of course, followed the mercury) will pass down through tubes *K* and *P*, into the pipette, *R*.

659. When the whole of the gas has passed out of the burette the mercury (which has now filled the burette) is allowed to flow through the capillary tubes, and when it has reached the lower part of the passage in cock *Q*, that cock and cock *J* are closed by turning each through 90° .

660. The pipette, *R*, may now be disconnected at joint *N* from the other part of the apparatus, and the inclosed gas agitated by the absorbing reagent.

661. After the absorption of the constituent gas the residue has now to be passed back into the burette, for the measurement of its volume; the level-bulb *W* being still in an elevated position, slightly open cock *J* again, making communication between the tubes *F'''* and *K*, and whilst the mercury is dropping from the lower end of the tube *K* connect the pipette at joint *N*; in this manner air will be excluded. The cock *J* is now fully opened, the level-bulb *W* is lowered, the cock *Q* carefully opened, and the mercury will be drawn

out of the capillary tubes, followed by the gas, and in turn by the reagent. As soon as the reagent has been drawn to the upper part of the passage in cock *J*, that cock is turned through 180° , making communication between tubes *L* and *F'''*. The mercury contained in the basin *M* will now be drawn upward through the capillary tubes *L F''' F'* and *F*, driving all the gas before it into the burette *A*.

662. When the whole of the gas has entered the burette the cock *E* is closed, the level-bulb is slightly raised, and the cock *E* carefully turned to make communication between the burette and the manometer tube *D*, the mercury in the two limbs of the manometer brought to the same level, the cock *V* then closed, and a reading taken of the volume of gas in the burette. As mentioned before, the true volume is equal to that read off plus the correction-constant; this total represents the column of residual gas, and the difference between this volume and the previous measurement will represent the volume of gas absorbed.

663. Previous to the next absorption it is necessary to wash the reagent out of the cock *J* and capillary tube *K*. Disconnect the last-employed pipette, open cock *G* and pour a little distilled water into the cup *H*; the water in running through the capillary tubes *F'' F'''* and *K* will cleanse those tubes. The water clinging to the tubes can be removed sufficiently by blowing with the mouth at the cup *H*. There will now be air in tubes *F'' F'''* and *K*, which can be displaced in the following manner:

664. Connect up the pipette containing the reagent necessary for the next following absorption, slip a piece of rubber tubing over the tubular end of the bulb, *T*, and gently blow with the mouth (the cock *Q* being open)—the reagent will be forced up the capillary tubes *P* and *K*, and when it has risen to the top of the passage in the cock *J* that cock is turned through 180° , making communication between tubes

F''' and L ; mercury is now poured in the cup H , and, running down to the basin M , will clear the air out of the tubes F'' F''' and L . The next absorption may now be proceeded with in the manner described in pars. 658 *et seq.*

665. The constituents of the gas mixture are determined in the following order and manner :

The benzene vapours are absorbed by passing the gas into an explosion pipette (Figs. 81 and 83) containing 1 cubic centimetre of absolute (ethyl) alcohol lying on the surface of the mercury; the pipette is cleared by the two cocks, disconnected from the other apparatus, and the gas and alcohol agitated; the gas is then drawn back into the burette, and passed into another pipette containing 1 cubic centimetre of water lying on the surface of the mercury, and is again shaken, so as to absorb the vapour of alcohol. The gas is then drawn back into the burette and measured. The resulting contraction gives the amount of benzene vapours present.

Note.—The explosion pipettes are first completely filled with mercury, and the alcohol and water are run in at N from burettes. Both the alcohol and the water are saturated with the gas for the less easily absorbable constituents before being used for the absorption of the benzene. If some of the gas is passed into each pipette and agitated with the liquids for several minutes, and the gas then driven out, the pipettes will be ready for use.

The carbon dioxide is next absorbed by a solution of potassium hydrate, contained in a pipette filled with small rolls of iron wire gauze. (Pipette, Fig. 78.)

The heavy hydrocarbons (ethylene, etc.) are absorbed in a pipette containing a solution of bromine in potassium bromide (pipette Fig. 77), or in one containing fuming sulphuric (Nordhausen) acid (Fig. 80); in either case the vapours of bromine or sulphuric acid must be removed by passing the gas into the potassium hydrate pipette before measurement.

The oxygen is absorbed by passing the gas into a pipette containing thin sticks of phosphorus covered by water (Fig. 78), or it may be absorbed in a pipette containing an alkaline solution of pyrogallous acid (Fig. 79). If the phosphorus pipette be used, care should be taken to ensure the complete absorption of the heavy hydrocarbons, which

otherwise will interfere with the action of the phosphorus. The pyrogallic acid pipette is, of course, a double one, to protect the reagent from the action of the air.

The carbon monoxide is absorbed either with an ammoniacal or a hydrochloric acid solution of cuprous chloride. Two pipettes should be used for this absorption (Fig. 79); the first containing a solution which has been frequently used, and the second containing a fresh solution, or at the least, one that has been used but little.

666. The results of the analysis of the gas mixture, we will assume, gave the following figures for the absorbable constituents:

AMOUNT OF GAS MIXTURE TAKEN FOR ANALYSIS =
100 CUBIC CENTIMETRES.

	C. Cm.	
Residue after absorption of benzene vapours	99.5	100.0 - 99.5 = 0.5 per cent.
Residue after absorption of carbon dioxide	97.5	99.5 - 97.5 = 2.0 “
Residue after absorption of heavy hydrocarbons	93.5	97.5 - 93.5 = 4.0 “
Residue after absorption of oxygen	93.3	93.5 - 93.3 = 0.2 “
Residue after absorption of carbon monoxide	84.5	93.3 - 84.5 = 8.8 “

Or, if the measurements are taken from the upper end of the burette and read downward, we have:

After the Absorption of the	The Measurement gave	Per Cent.
Benzene vapours	0.5 cu. cent.	= 0.5
Carbon dioxide	2.5 “	2.5 - 0.5 = 2.0
Heavy hydrocarbons . . .	6.5 “	6.5 - 2.5 = 4.0
Oxygen	6.7 “	6.7 - 6.5 = 0.2
Carbon monoxide	15.5 “	15.5 - 6.7 = 8.8

NOTE. It is to be understood that, in all cases, the gas in the burette is brought under atmospheric pressure before the volume is read off, and that the correction-constant is added to the observed volume.

667. The unabsorbed residue amounts to 84.5 cubic centimetres. Its constituents are determined by mixing a portion with oxygen or air and exploding over mercury in the explosion pipette (Fig. 83). The contraction in volume is measured; the carbon dioxide formed is determined by

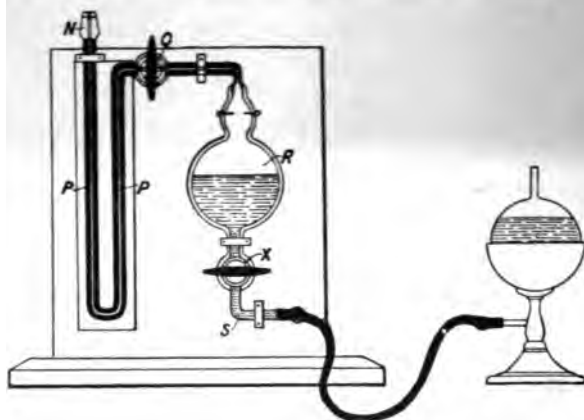


FIG. 83.—EXPLOSION PIPETTE (TAPLEY'S APPARATUS).

absorption in the potassium hydrate pipette; the excess of oxygen is absorbed in the phosphorus, or in the alkaline solution of pyrogallic acid pipette; and the volume of the residual nitrogen is noted. Since only from 12 to 15 cubic centimetres of this residue are required for the explosion, the remaining quantity may conveniently be stored in the second cuprous chloride pipette, in case another portion of the residue is required to check the first explosion, or owing to loss of the gas due to accidental causes.

668. The manipulation is as follows: The cock *E* being turned so that the burette communicates with the capillary

tube *F*, and the cock *J* turned so as to make communication between capillary tubes *F'''* and *L*, open cock *V* and rise the level-bulb *W*, and as soon as the mercury is displaced from the capillary tubes and the gas appears at the bottom of the tube *F'''* turn the cock *J* through 180°, causing communication between capillary tubes *F'''* and *K*, and open cock *Q*,—the gas will now pass into the cuprous chloride pipette. When all but about 12 to 15 cubic centimetres of the gas residue has been driven over into the pipette, the cock *J* is again turned so that the capillary tubes *F'''* and *L* are in communication, and the level-bulb is lowered; the mercury will be drawn out of the basin, *M*, displacing the gas from the capillaries *F''' F' F*. The gas in the burette is now brought under atmospheric pressure and its volume noted; let it be assumed that the volume of gas to be exploded is 14.0 cubic centimetres.

669. The capillary tubes *K* and *P* are now cleared of the gas by pouring mercury in the cup *H*, opening cock *G* and applying gentle suction at open end of bulb *T* of the pipette; a piece of cotton wool should be placed in the tube before applying the mouth for suction. As soon as the mercury descends to the lower end of the passage in cock *Q*, that cock is closed, and the pipette may now be disconnected.

670. Air or oxygen is now to be drawn into the burette. If oxygen is to be used, it may be introduced from an explosion pipette by connecting at joint *N*; from 1.5 to 2 times the volume of the gas residue must be allowed to enter the burette.

$$\begin{array}{rcl}
 \text{Say volume of gas residue} & = & 14.0 \text{ c.cm.} \\
 \text{" " oxygen employed} & = & 24.0 \text{ " } \\
 \hline
 \text{Total mixture} & = & 38.0 \text{ " }
 \end{array}$$

If air is to be used, so much is drawn in that the total volume of the gas residue taken, and the air admitted, amounts to

about 100 cubic centimetres. When the requisite amount of air has been drawn into the burette all the capillary tubes are cleared of the air.

Say volume of gas residue	= 14.0 c.cm.
" " " air employed	= 85.4 "
Total mixture	99.4 "

671. Now completely fill the explosion pipette and capillary tube attached with mercury by raising the level-bulb connected with the pipette; pour a little mercury in cup *H*, and as it runs down from capillary tube *K*, connect up the explosion pipette at joint *N*, and close the cock *X* of the same pipette (Fig. 83). The mixed gas residue and air (or oxygen) is now passed from the burette into the explosion pipette, and is followed by the mercury, which should fill that portion of the capillary tube between the cock *Q* and the platinum wires fused into the glass of the pipette. The upper cock *Q* is now closed, the pipette disconnected at joint *N* and then vigorously shaken so as to thoroughly mix the gas and air (or oxygen).

672. It is now necessary to so arrange the pressure of the gas within the pipette that the explosion is neither too violent nor too mild. If too high a pressure be employed the explosion will be too violent and some of the nitrogen of the gas residue and the oxygen employed may combine directly to form oxides of nitrogen; the pipette may also be shattered by the force of the explosion. If too low a pressure be employed, incomplete combustion of the hydrocarbons takes place and some carbon monoxide is formed, instead of carbon dioxide only. The exploding pressure depends upon the proportion of combustible gas introduced. If oxygen be mixed with the portion of residual gas the pressure required would not be so great as that necessary for explosion when air is mixed with the portion of gas residue, because, in the

latter case, the addition of the comparatively large amount of atmospheric nitrogen, being an inert gas, may lead to imperfect combustion, the cooling effect of this gas reducing the temperature below that required.

673. As no hard-and-fast line can be laid down regarding the exploding pressures of these gas mixtures, experience must guide the operator to determine to what extent the mixed gases shall be expanded in order to obtain satisfactory results. Assistance in this direction may be obtained by bringing the mixed gases within the explosion pipette to the pressure of the atmosphere by means of the level-bulb, which latter is then kept in the required position by wood blocks placed beneath it; the open end of the level-bulb is now connected by means of rubber tubing to a U-tube containing mercury and acting as a pressure-gauge; this gauge may conveniently be fixed on the back of the wooden board which supports the measuring burette. Upon lowering the level-bulb the mercury will flow into it from the explosion pipette, causing the mixed gases contained in the latter to expand; the air inclosed in the space between the surface of the mercury in the level-bulb and that in the U-tube will at the same time be under pressure; this pressure may be recorded on a scale attached to the U-tube. Blank experiments should be made, and when satisfactory results are obtained (*i. e.*, when the explosion does not cause the formation of either carbon monoxide or nitrogen oxides) the pressures recorded by the U-tube and employed for the particular kind of gas under analysis may be noted for future reference.

674. We will now proceed with the analysis of the gas residue, which was mixed with air in the following proportions:

$$\begin{array}{rcl}
 \text{Volume of gas residue taken} & = & 14.0 \text{ c.cm.} \\
 \text{" " air employed} & = & 85.4 \text{ " } \\
 \text{Total volume} & = & 99.4 \text{ " }
 \end{array}$$

This mixture, having been passed into the explosion pipette (see par. 671), is expanded in the manner described above, the two stop-cocks *Q* and *X* are closed, and the wires from a small induction coil (connected to a six-cell bichromate battery) are joined to the platinum loops fused into the glass of the explosion pipette, and a spark is passed through the mixed gases. The inclosed gases should combine with just sufficient activity as to produce a distinct sound, but without violence. The lower stop-cock *X* is then opened and the pipette connected up to the capillary tube *K*, and manipulated so as to exclude air (as previously described). The remaining gas is now transferred to the measuring burette *A*, and, after cooling, its volume is measured at atmospheric pressure. The volume read off was 76.0 cubic centimetres.

$$\begin{array}{rcl}
 \text{Volume of gases before explosion} & = & 99.4 \text{ c.cm.} \\
 \text{" " " after} & = & 76.0 \text{ " } \\
 \text{The total contraction is therefore} & & 23.4 \text{ " }
 \end{array}$$

675. The gas left after the explosion is now passed into the potassium hydrate pipette, in order to absorb the carbon dioxide which has been formed by the combustion of the hydrocarbons. The residue is drawn back into the burette and measured.

$$\begin{array}{rcl}
 \text{Volume of gases before absorption of CO}_2 & = & 76.0 \text{ c.cm.} \\
 \text{" " " after} & = & 70.5 \text{ " } \\
 \text{Volume of CO}_2 \text{ formed} & = & 5.5 \text{ " }
 \end{array}$$

678. In order to be quite sure that an excess of oxygen (air) was employed for the combustion, the gas remaining after the absorption of the CO_2 is passed either into the phosphorus pipette, or the pipette containing the alkaline solution of pyrogalllic acid, and the residual gas is drawn back into the burette and measured.

Volume of gases before absorption of excess oxygen	= 70.5 c.cm.
Volume of gases after absorption of excess oxygen	= 67.9 "
Volume of oxygen in excess	= 2.6 "

We have now the data necessary for the calculation of the methane and hydrogen.

679. *Marsh-gas, or Methane* (CH_4).—In the combustion of methane this gas unites with twice its volume of oxygen, with the production of its own volume of carbon dioxide, the contraction resulting from this combustion being equal to twice the volume of the methane present, and caused by the production of water vapour. The volume of CO_2 formed was found to be 5.5 cubic centimetres, therefore, in the 14.0 cubic centimetres of residual gas taken for explosion there were 5.5 cubic centimetres of methane. The amount of methane in the total gas residue, viz., 84.5 cubic centimetres, will be:

$$\frac{84.5 \text{ c.cm.} \times 5.5 \text{ c.cm.}}{14 \text{ c.cm.}} = 33.2 \text{ per cent. of methane.}$$

680. *Hydrogen*.—We have seen that methane, during combustion, unites with twice its volume of oxygen; and as hydrogen, during the combustion, unites with one-half its volume of oxygen, the total contraction, viz., 23.4 cubic centimetres, may be represented by $(1.5 h + 2 m)$, where h = hydrogen and m = methane.

$$(1.5 h + 2 m) = 23.4 \text{ c.cm.}$$

The value of m we have previously found to be 5.5 cubic centimetres. The contraction due to the combination of the hydrogen will therefore be:

$$\frac{3}{2}h + 2(5.5) = 23.4 \text{ c.cm.}$$

$$\frac{3}{2}h + 11.0 = 23.4 \text{ c.cm.}$$

$$\text{or, } \frac{3}{2}h = 23.4 - 11.0 = 12.4 \text{ c.cm.}$$

and the volume of the hydrogen present in the 14 cubic centimetres of residual gas taken for explosion will be:

$$\frac{3}{2}h = 12.4 \text{ c.cm.}$$

Therefore, $h = 12.4 \times \frac{2}{3} = 8.27 \text{ c.cm. of hydrogen.}$

In other words, the hydrogen is calculated by subtracting twice the volume of the carbon dioxide found from the total contraction and then multiplying that result by $\frac{2}{3}$.

The amount of hydrogen in the total gas residue of 84.5 cubic centimetres will be:

$$\frac{84.5 \times 8.27}{14} = 49.9 \text{ per cent. of hydrogen.}$$

681. *Nitrogen*.—The nitrogen may be found by subtracting the sum of the hydrogen and methane found in the portion exploded from the quantity taken for explosion:

Methane found =	5.5 c.cm.	Gas taken for	
Hydrogen " =	8.27 "	explosion =	14.0 c.cm.
		(h + m)	= 13.77 "
Total	= 13.77 "	Nitrogen	= 0.23 "

$$\text{and, } \frac{84.5 \times 0.23}{14} = 1.39 \text{ (say 1.4) per cent. of nitrogen.}$$

The nitrogen may be found also by subtracting the sum of all the other constituents from 100. (See also pars. 642 and 643.)

682. From the analysis, this sample of ordinary coal-gas contained the following:

Name	Formula	Per cent
Hydrocarbon (benzene) vapours.....	C_6H_6	0.5
Carbon dioxide.....	CO_2	2.0
Heavy hydrocarbons (ethylene).....	C_3H_4	4.0
Oxygen.....	O_2	0.2
Carbon monoxide.....	CO	8.8
Methane.....	CH_4	33.2
Hydrogen.....	H_2	49.9
Nitrogen (by difference).....	N_2	1.4
Total.....		100.0

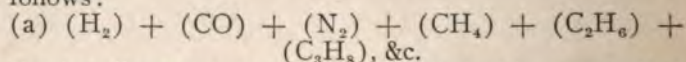
683. Below is a table of the principal gases and vapours, with the quantity of oxygen necessary for combustion, and the volumes of products resulting:

One Volume of	Formula	Requires Volumes of Oxygen	Volumes of Products		Contraction after Explosion
			H_2O	CO_2	
Carbon monoxide.....	CO	0.5	...	1.0	0.5
Hydrogen.....	H_2	0.5	1.0	...	1.5
PARAFFINES—	$C_n H_{2n+2}$				
Methane.....	CH_4	2.0	2.0	1.0	2.0
Ethane.....	C_2H_6	3.5	3.0	2.0	2.5
Propane.....	C_3H_8	5.0	4.0	3.0	3.0
Butane.....	C_4H_{10}	6.5	5.0	4.0	3.5
Pentane.....	C_5H_{12}	8.0	6.0	5.0	4.0
Hexane.....	C_6H_{14}	9.5	7.0	6.0	4.5
OLEFINES—	$C_n H_{2n}$				
Ethylene.....	C_2H_4	3.0	2.0	2.0	2.0
Propylene.....	C_3H_6	4.5	3.0	3.0	2.5
Butylene.....	C_4H_8	6.0	4.0	4.0	3.0
Amylene.....	C_5H_{10}	7.5	5.0	5.0	3.5
Hexylene.....	C_6H_{12}	9.0	6.0	6.0	4.0
	$C_n H_{2n-2}$				
Acetylene.....	C_2H_2	2.5	1.0	2.0	1.5
Allylene.....	C_3H_4	4.0	2.0	3.0	2.0
	$C_n H_{2n-6}$				
Benzene.....	C_6H_6	7.5	3.0	6.0	2.5
Toluene.....	C_7H_8	9.0	4.0	7.0	3.0

684. In the foregoing calculations it has been supposed that there are present no higher paraffines than methane, but if the coal-gas has been enriched, either by carburetted water-gas or by some light petroleum naphtha, a modification, both in the manipulation of the residual gases and also in the subsequent calculation of the results, is necessary.

685. In the *Journal of Gas Lighting* for September 27, 1898, is an article (taken from the *Journal of the Franklin Institute*) by E. H. Earnshaw dealing with this matter of higher paraffines. Paragraphs 686 to 705 are part of the text of the article. After introducing the subject of gas analysis, and stating that the carbon monoxide is seldom completely absorbed (even after using a perfectly fresh solution contained in the last pipette); that usually about 0.5 per cent. remains unabsorbed, and that the residue of carbon monoxide can be determined later. The article goes on to state that

The residue of the gas mixture now remaining may be as follows:



But for all ordinary purposes it is sufficient to assume that the only higher paraffine present is C_2H_6 .

There being no satisfactory known absorbent for any of these gases, it becomes necessary to have recourse to the method of combustion.

686. A portion of (a) is then mixed with a measured volume of air, and exploded over mercury in an explosion pipette. The contraction in volume is measured; the carbon dioxide formed is determined by absorption with potassium hydrate; the excess of oxygen is absorbed by phosphorus, and the volume of the residual nitrogen is noted.

The equations are:

$$(1) \text{ Contraction in volume} = \frac{3}{2}(H_2) + \frac{1}{2}(CO) + 2(CH_4) + 2\frac{1}{2}(C_2H_6)$$

$$(2) CO_2 \text{ formed} = (CO) + (CH_4) + 2(C_2H_6)$$

$$(3) \text{ Residual nitrogen} = (N_2) + (N_1),$$

where N_1 is the nitrogen introduced with the air. The

amount of nitrogen thus introduced may, with sufficient accuracy be taken at 79.2 per cent. of the measured volume of air.

687. An examination of these equations shows that the nitrogen may at once be ascertained from Equation 3; but Equations 1 and 2 contain four unknown quantities, and therefore two more equations are needed for the solution. Fortunately the method of fractional combustion over palladium affords the needed information. As is well known, when a mixture of hydrogen and methane with oxygen or air is passed, with the proper precaution, over heated palladium black, the hydrogen burns to water; but the methane is unaltered. If carbonic oxide and any of the higher paraffines are also present, the carbonic oxide burns, but the paraffines do not. If, then, the products from the combustion are received in a pipette over mercury it is possible to subsequently measure the amount of carbonic acid formed by the burning of the carbonic oxide.
688. Returning to the analysis, a second portion of (a) is taken, mixed with air, and burned over palladium black. The resulting contraction and the carbonic acid formed are measured. The equations are:

$$(4) \text{ Contraction in volume} = \frac{3}{2} (\text{H}_2) + \frac{1}{2} (\text{CO}).$$

$$(5) \text{ CO}_2 \text{ formed} = \text{CO}.$$

From these two equations the values for hydrogen and carbonic oxide may be readily calculated.

689. For simplicity's sake let us now assume that the same quantity of gas mixture (a) was used in both the explosion and the combustion. We may then subtract Equation 4 from 1, and 5 from 2, whence, designating the difference between the contraction due to explosion and that due to combustion by the letter "a" and the difference in the carbonic acid formed by the letter "b," we find:

$$(6) 2(\text{CH}_4) + 2\frac{1}{2} (\text{C}_2\text{H}_6) = a.$$

$$(7) (\text{CH}_4) + 2(\text{C}_2\text{H}_6) = b.$$

$$(8) \text{ whence } \text{C}_2\text{H}_6 = \frac{4b - 2a}{3}.$$

$$(9) \text{ CH}_4 = \frac{4a - 5b}{3}.$$

A very useful check on the accuracy of this determination is obtained from the following:

Volume of gas taken for explosion $= \text{H}_2 + \text{N}_2 + \text{CO} + \text{CH}_4 + \text{C}_2\text{H}_6$. H_2 and CO are found by Equations 4 and 5, and N_2 is given by Equation 3. Therefore we have:

(10) Volume taken $-(\text{H}_2 + \text{N}_2 + \text{CO}) = \text{CH}_4 + \text{C}_2\text{H}_6$; and this value should be the same as the algebraic sum of Equations 8 and 9; or—

$$(11) \text{ Volume taken } - (\text{H}_2 + \text{N}_2 + \text{CO}) = \frac{2a - b}{3}.$$

690. This scheme of analysis is perfectly correct for gas mixtures containing no higher paraffine than C_2H_6 ; but what would happen in case C_3H_8 , C_4H_{10} , etc., were present?

Our gas mixture would then contain P volumes of hydrocarbons of the formula $\text{C}_n\text{H}_{2n+2}$, and would be:

Gas mixture $= \text{H}_2 + \text{N}_2 + \text{CO} + P(\text{C}_n\text{H}_{2n+2})$.

As will be shown later, the contraction in volume due to the combustion of P volumes of any hydrocarbon of the general formula CH_{n+m} would be

$$P \left(1 + \frac{m}{4} \right)$$

and the carbonic acid formed would be Pn . But in this case, $m = n + 2$ (the gas being a paraffine, see par. 683 J. A.), and therefore we have,

From the explosion:

(12) Contraction in volume

$$= \frac{3}{2} (\text{H}_2) + \frac{1}{2} (\text{CO}) + \frac{Pn + P}{2} + P.$$

(13) Carbonic acid formed $= Pn + \text{Co}$.

And from the combustion over palladium:

$$(14) \text{ Contraction in volume } = \frac{3}{2} (\text{H}_2) + \frac{1}{2} (\text{CO}).$$

(15) Carbonic acid formed $= \text{CO}$.

Subtracting Equation 14 from 12 and 15 from 13, as before explained, we have,

(16) Difference in contraction

$$P + \frac{Pn + P}{2} = a$$

(7) Difference in carbonic acid formed $= Pn = b$; whence,

$$(18) \quad P = \frac{2a - b}{3}$$

$$(19) \quad n = \frac{3b}{2a - b}.$$

Equation 18 is identical with Equation 11; and hence it appears that the method is correct as far as the total volume of paraffines is concerned, even though higher paraffines than C_2H_6 are present.

691. Having thus examined the theory of the analysis by combustion, let us follow the figures of an actual analysis.

The gas was a water gas, enriched by naphtha, and its candle power was 23.5.

Amount taken for analysis. 100.0 c.c.

	Per cent.
C_6H_6 absorbed by alcohol.	0.4
CO_2 absorbed by potash	2.7
Illuminants absorbed by bromine	11.7
Oxygen absorbed by phosphorus	0.5
Carbonic oxide absorbed by cuprous chloride	31.7

Of the unabsorbed residue of 53 c.c. 14.05 c.c. were mixed with 87.8 c.c. of air, and exploded by a spark in an explosion pipette over mercury. The resulting contraction in volume was 22.60 c.c. The carbonic acid absorbed by potash was 5.30 c.c.; the surplus oxygen absorbed by phosphorus, 3.80 cc.; the residual nitrogen, 70.1 c.c. consisting of nitrogen from the air, 69.50 c.c., and nitrogen from the gas, 0.60 c.c.

A second portion of 30 c.c. was now mixed with 70 c.c. of air, and the mixture passed over palladium black to burn the hydrogen and carbonic oxide.

The contraction in volume was 30.40 c.c.

The carbonic acid absorbed by potash was 0.40 c.c.

692. To calculate the percentage of H, CO, CH_4 , C_2H_6 , and N according to the method already theoretically explained, we proceed thus:

$$CO = \frac{0.4 \times 53}{30} = 0.70 \text{ per cent.}$$

$$H = \frac{(30.4 - 0.2) \times 53}{30} \times \frac{2}{3} = 35.57 \text{ per cent.}$$

Now, as 30 c.c. of gas were taken for the combustion and only 14.05 c.c. for the explosion, we must calculate the contraction in volume and amount of carbonic acid that

would have resulted from the combustion of 14.05 c.c. over palladium. Thus—

Contraction in volume would be

$$= \frac{30.4 \times 14.05}{30} = 14.24$$

CO₂ formed would be

$$= \frac{0.40 \times 14.05}{30} = 0.18$$

Subtracting these figures from the results of the explosion, we find,

$$\begin{aligned} 22.60 - 14.24 &= 8.36 = a \\ 5.30 - 0.18 &= 5.12 = b \end{aligned}$$

and hence, from Equations 8 and 9

$$C_2H_6 = \frac{20.48 - 16.72}{3} = 1.25$$

$$CH_4 = \frac{33.44 - 25.60}{3} = 2.61,$$

and therefore,

$$\begin{aligned} C_2H_6 \text{ in original gas} \\ &= \frac{1.25 \times 53}{14.05} = 4.71 \text{ per cent.} \end{aligned}$$

$$\begin{aligned} CH_4 \text{ in original gas} \\ &= \frac{2.61 \times 53}{14.05} = 9.84 \text{ per cent.} \end{aligned}$$

$$\begin{aligned} N \text{ in original gas} \\ &= \frac{0.60 \times 53}{14.05} = 2.26 \text{ per cent.} \end{aligned}$$

Applying Equation 11 as a check on the accuracy of the determination, we find—

$$14.05 - (9.43 + 0.60 + 0.18) = \frac{2(8.36) - 5.12}{3},$$

or, 3.84 = 3.86, which is a difference well within the limit of errors of observation.

693. In the calculation of this analysis we have assumed for convenience sake that there are no paraffines present other than CH₄ and C₂H₆. Of course, it is possible, and in-

deed probable, that higher members of the series are actually present; so that while the figures obtained in our calculations truly represent the total quantity of paraffines contained in the gas, yet they may not be true as regards the actual composition. The composition of the average molecule of the paraffines may be obtained from Equation 19, thus—

$$n = \frac{15.36}{16.72 - 5.12} = 1.32,$$

whence the average composition of the paraffines C_nH_{2n+2} would be: C, 1.32; H, 4.64.

694. The value of this method in giving an accurate conception of the actual composition of a gas mixture is clearly brought out by comparing the figures just given with those obtained by the more usual methods of calculation. These methods are: (1) When no combustion over palladium is made, and the hydrogen is determined by subtracting twice the volume of carbonic acid formed in the explosion from the contraction in volume, and calling the difference the contraction due to hydrogen. (2) The method recommended by Hempel, who directs that the hydrogen should be determined by combustion over palladium. The contraction in volume due to the percentage of hydrogen thus found is subtracted from the total contraction due to the explosion, and the remainder is considered to be the contraction due to CH_4 , which is, of course, equal to twice the volume of CH_4 . Both these methods presuppose that no paraffine other than CH_4 is present, and that the carbonic oxide has been completely absorbed by cuprous chloride.

	Calculated by Method Given Above	By Method with- out Combustion over Palladium	By Method according to Hempel
Benzene vapours	0.40	0.40	0.40
Fixed illuminants	11.70	11.70	11.70
Carbonic oxide	32.40	31.70	31.70
Hydrogen	35.57	30.34	35.84
Paraffines C_2H_6	4.71	—	—
Paraffines CH_4	9.84	20.00	16.30
Carbonic acid	2.70	2.70	2.70
Oxygen	0.50	0.50	0.50
Nitrogen (by difference)	2.18	2.66	0.86
	100.00	100.00	100.00

The method without separate determination of hydrogen is the simplest both in method and in apparatus required, and is, therefore, the one in most general use.

695. In the analysis of water gas by this method, let us consider the equations resulting from the explosion of 15 cubic centimetres of a gas mixture composed of—

H	10.0 c.c.
CH ₄	3.0 "
C ₂ H ₆	1.5 "
N	0.5 "
	15.0 "

The resulting equations would be:

Contraction in volume

$$= \frac{3}{2}(\text{H}_2) + 2(\text{CH}_4) + 2\frac{1}{2}(\text{C}_2\text{H}_6) = 24.75$$

Carbonic acid formed

$$= (\text{CH}_4) + 2(\text{C}_2\text{H}_6) = 6.00$$

Volume of gas taken

$$= \text{H}_2 + \text{CH}_4 + \text{C}_2\text{H}_6 + \text{N}_2 = 15.00$$

Nitrogen

$$= \text{N}_2 = 0.50$$

At first it would seem that these equations could be easily solved, and that no more data would be required for the correct computation of the composition of the gas mixture. An attempt to solve the equations, however, discloses the fact that the problem is indeterminate, and that the equations can be satisfied by any value of C₂H₆ from 0 to 3. Thus:

Let C ₂ H ₆ ... = 0,	Let C ₂ H ₆ ... = 3,
Then, H ₂ = 8.50	Then, H ₂ = 11.50
CH ₄ = 6.00	CH ₄ = 0.00
C ₂ H ₆ = 0.00	C ₂ H ₆ = 3.00
N ₂ = 0.50	N ₂ = 0.50
15.00	15.00

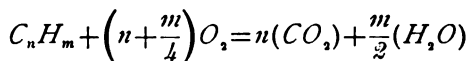
We may perhaps find in this circumstance an explanation for the continued use of this method by many analysts without suspecting the incorrect application to gas mixtures containing higher paraffines than methane. The

analysis would always "add up well," and the amount of nitrogen found would be correct.

696. I have now indicated a method by which we may obtain a very fair idea of the composition of a gas mixture—sufficient, indeed, for most purposes. But the use of gas as a source of heat is constantly increasing, and I believe the time is not far distant when the heating value of a gas will be considered as important as its illuminating power. It is, therefore, extremely desirable to be able to accurately calculate the heating value of a gas from its analysis. The labours of many able investigators (and notably those of Professor Julius Thomsen) have supplied us with reliable data concerning the heating value of each of the several combustible gases entering into the composition of illuminating gas; and, therefore, the problem would offer no special difficulty were it not for the uncertainty regarding the nature of the hydrocarbons removed by bromine, and classed together as "fixed illuminants." We know that these consist chiefly of the series C_nH_{2n} , together with very small quantities of the C_nH_{2n-2} series; but the quantitative separation of the different members is not at present possible within the limits of a technical analysis.

697. If, however, we should succeed in determining the average composition of the hydrocarbons, and should be able to assign a definite heating value, depending upon such average composition, then the problem would be completely solved as far as its practical application is concerned.

The theory of the combustion of any hydrocarbon or mixture of hydrocarbons, of which the unit volume has the average composition C_nH_m , is as follows:



But in practice the $\frac{m}{2}$ volumes of water disappear; and, therefore, we have—

Contraction in volume

$$= 1 + \left(n + \frac{m}{4}\right) - n = 1 + \frac{m}{4}$$

Carbonic acid formed = n .

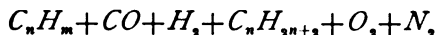
If we let a = contraction in volume for x volumes $C_n H_m$
 $b = CO_2$ formed for x volumes $C_n H_m$, then we find,

$$(20) \quad m = \frac{4(a-x)}{x}$$

$$(21) \quad n = \frac{b}{x}$$

698. It is now apparent that if we can by any means determine the contraction in volume and the amount of carbonic acid that would be formed by the combustion of a known volume of the illuminants in a gas mixture, then we shall have all the data necessary for the correct computation of the average composition of such illuminants. This can be done very simply and accurately thus:

First absorb the unfixed vapours by alcohol, and the carbonic acid by potassium hydrate. The residual gas will have the composition—



Take a portion of this, mix it with the proper amount of air, and explode the mixture by a spark in the ordinary way. Note the resulting contraction in volume, and the amount of the carbonic acid formed.

The contraction in volume will consist of—

- (1) Contraction due to $C_n H_m$,
- (2) " " CO ,
- (3) " " H_2 ,
- (4) " " $C_n H_{n+2}$,

and the carbonic acid formed will consist in like manner—

- (1) CO_2 due to $C_n H_m$,
- (2) " " CO ,
- (3) " " $C_n H_{n+2}$.

699. If, now, we proceed with the analysis and determine the percentage of each constituent by the method already described, we shall be able to calculate the contraction due to CO , H_2 , and $C_n H_{n+2}$, and the CO_2 due to CO and $C_n H_{n+2}$. This will give us the contraction in volume and the CO_2 due to $C_n H_m$ alone and hence the data required.

In practice, it is simpler to calculate the correction for the paraffines and hydrogen directly from the results of the explosion rather than from the percentages of these gases; but this will be made plainer by considering the actual figures of an analysis.

700. Taking for illustration the same sample of water gas as before, the notes of the analysis would be:

	Cubic Centimetres	Per Cent
Amount taken for analysis.....	100.00	
Residue after absorbing the unfixed vapours and the carbonic acid	96.90 (a)	
<i>First Explosion.</i>		
Portion of (a) taken	12.00	
Mixed with 87.8 cubic centimetres of air and exploded:		
Resulting contraction in volume.....	16.05	
Carbonic acid absorbed by potash.....	10.55	
Excess oxygen absorbed by phosphorus	3.40	
Residue from (a)	84.90	
Fixed illuminants absorbed by bro- mine	10.25 = 11.70	
Oxygen absorbed by phosphorus.....	0.44 = 0.50	
Carbonic oxide absorbed by cuprous chloride	27.78 = 31.70	
Residue (b)	46.45 = 53.00	
<i>Second Explosion.</i>		
Portion of (b) taken	14.05	
Mixed with 87.8 cubic centimetres of air and exploded:		
Resulting contraction in volume....	22.60	
Carbonic acid absorbed by potash....	5.30	
Excess oxygen absorbed by phosphorus	3.80	

The amount taken for the first explosion was $\frac{12}{96.9} =$

.1237 of the original quantity; and we can, therefore, calculate that it was composed of—
the average composition C_nH_m , is as follows:

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	Per Cent.	Cubic Centimetres
Fixed illuminants	11.70 × .1237	1.45
Oxygen	0.50 × "	0.06
Carbonic oxide	31.70 × "	3.93
Residue (b)	53.00 × "	6.56
		12.00

The contraction and carbonic acid resulting from the explosion of 14.05 cubic centimetres of residue (b) having been determined by the second explosion, we can, of course, readily calculate the results due to the combustion of 6.56 cubic centimetres.

The results of the first explosion can now be tabulated thus:

	Carbonic Acid Contraction Cubic Centimetres
1.45 cubic centimetres of fixed illuminants (C_nH_m) gives	4.15 3.56
3.93 cubic centimetres of carbonic oxide gives	3.93 1.96
6.56 cubic centimetres of residue (b) gives	2.47 10.53
	10.55 16.05

and hence, from Equations 20 and 21,

$$m = \frac{4(3.56 - 1.45)}{1.45} = 5.82$$

$$n = \frac{4.15}{1.45} = 2.86$$

and, therefore, the average composition of the fixed illuminants C_nH_m is: C, 2.86; H, 5.82.

701. Professor Julius Thomsen in his "Thermo-Chemical Investigations," Vol. IV., p. 275, gives the general formula for the calculation of heat of combustion of any hydrocarbon of the formula C_nH_m , expressed in calories per molecular weight in grammes of the hydrocarbon, thus:

$$f = n \cdot 135340 + m \cdot 37780 - a \cdot 14200 + 580.$$

For the olefine series, C_nH_{2n}

$$n = m$$

$$a = n - 1$$

and, therefore, translating the formula into English units, we find for the heat of combustion of any hydrocarbon, or mixture of hydrocarbons of the general formula C_nH_{2n}

$$\text{B. T. U. per cubic foot} = n (757) + 70.$$

$$\text{B. T. U. per pound} = 20432 + \frac{1900}{n}$$

For the paraffine series, C_nH_{2n+2} ,

$$m = n + 1$$

$$a = n - 1$$

and, therefore, we find for the heat of combustion—

$$\text{B. T. U. per cubic foot} = n (757) + 251$$

$$\text{B. T. U. per pound} = 20432 + \frac{53744}{14n + 2}$$

702. We found the composition of the illuminants to be $C_{2.86}H_{5.82}$; and this approaches so closely to the composition of olefines, that for all practical purposes we may consider the fixed illuminants as belonging entirely to that series.

Therefore, calculating the average heating value of the illuminants from the formula for the olefines, we have:

Illuminants, $C_{2.86}H_{5.82} = 2235$ B. T. U. per cubic foot

We found the average composition of the paraffines to be $C_{1.32}H_{4.64}$; and hence, from the formula for the paraffines, the average heating value would be:

Paraffines, $C_{1.32}H_{4.64} = 1250$ B. T. U. per cubic foot.

703. We have shown that the determination of the total amount of paraffines in a gas mixture is not affected by considering CH_4 and C_2H_6 to be the only two members of the series present; and it is also true that the calculation of the heating value is unaltered by the same assumption. This may be shown thus:

The percentage of paraffines present and their composition was found by the analysis to be—

14.55 p. c. $C_{1.32}H_{4.64} = 4.71$ p. c. $C_2H_6 + 9.84$ p. c. CH_4 .

The calculation of the heating value would be—

0.1455 cu. ft. $C_{1.32}H_{4.64} \times 1250 = 182.9$ B. T. U.

0.0471 " $C_2H_6 \times 1764.4 = 83.1$ } 182.3 B.T.U.

0.0984 " $CH_4 \times 1009 = 99.2$ }

Thus the result is the same with each method of calculation.

704. The heating values obtained by Professor Julius Thomsen for the principal constituents of illuminating gas are

given in the following table. Thomsen's original figures are given in calories per molecular weight of the substance in grams; and I have translated these into English units per cubic foot. The temperature of the products of combustion is assumed to be reduced to 18° C., or 64.4° Fahr.

Name	Molecular Formula	Calories per Molecular Weight in Grams	B. T. U.'s per Cubic Foot at 60° and 30°
Hydrogen	H ₂	68,360	326.2
Carbonic oxide.	CO	67,960	323.5
Methane	CH ₄	211,930	1009.2
Ethane	C ₂ H ₆	370,440	1764.4
Propane	C ₃ H ₈	529,210	2521.0
Butane	C ₄ H ₁₀	687,190	3274.0
Ethylene	C ₂ H ₄	333,350	1588.0
Propylene	C ₃ H ₆	492,740	2347.2
Butylene	C ₄ H ₈	650,620	3099.2
Acetylene	C ₂ H ₂	310,050	1476.7
Benzene	C ₆ H ₆	799,350	3807.4

705. Returning once more to our analysis, the calculation of the heating value of 1 cubic foot of the water gas would be:

0.0040 cu. ft.	C ₆ H ₆ × 3807.4	= 15.2 B.T.U.
0.1170 "	C _{2.86} H _{5.82} × 2235	= 261.5 "
0.3240 "	CO × 323.5	= 104.8 "
0.3557 "	H ₂ × 326.2	= 116.0 "
0.0471 "	C ₂ H ₆ × 1764.4	= 83.1 "
0.0984 "	CH ₄ × 1009.0	= 99.2 "
0.0538 "	CO ₂ + O ₂ + N ₂	= 0.0 "
1.0000		679.8 "

As mentioned before, pars. 686 to 705 are taken from an article by E. H. Earnshaw, and published in the "Journal of Gas Lighting," for September 27, 1898.

NOTE.—The method of fractional combustion over pal-

ladium is given in Hempel's "Methods of Gas Analysis," pp. 133 to 148.

706. As the nitrogen in a gas mixture is estimated by difference, it follows that all the errors of the preceding determinations fall upon the nitrogen, therefore, every care should be taken in the performance of the experiments. Incomplete absorption of the constituents is one of the faults; the proper explosion pressure must be employed, and the whole of the apparatus should be in thoroughly good working order.

707. J. Kent Smith (in the *Journal Soc. Chem. Industry*, 1899, p. 213) gives particulars of a method for the estimation of nitrogen in gases. The method is as follows:

The gas to be tested passes through an experimental meter into an expansion bottle, and from thence through a Dreschel or similar flask containing a layer of H_2SO_4 , into a combustion tube packed with ignited asbestos fibre at each end, and filled with metallic copper and copper oxide. The expansion bottle has a cork provided with four holes for the insertion of the following: (1) Inlet tube; (2) outlet tube; (3) thermometer; (4) water-gauge. The gases escaping from the combustion tube are led through a pneumatic trough into a receiver, consisting of a bottle, the capacity of which has been exactly determined, and the neck capable of being filled by a one-hole rubber stopper carrying a capillary glass tap. The hydrocarbons, etc., in coal-gas, when passed through the foregoing apparatus, with the combustion tube heated in a laboratory furnace, are oxidised by the red-hot copper into CO_2 , SO_2 , and H_2O , the nitrogen remained unchanged.

708. In making a test the gases are allowed to flow through the apparatus for some time before collecting the resultant gases, which consist of CO_2 and N_2 only, the SO_2 produced being absorbed by the sulphuric acid and water in the pneumatic trough and in the water-vapour condensed out. In carrying out a test the measured bottle is slipped

over the issuing bubbles, and the meter read simultaneously. When the bottle is filled to the measured mark it is slipped away, taking care to keep the mouth under water, and the meter again read. The bung and tap is then inserted and the bottle placed in an inverted position on a convenient stand, suction applied, and enclosed water taken out. Strong NaHO solution is then sucked up, the tap closed, and the bottle well shaken to absorb the CO_2 . The bottle is then again placed in water and tap opened, then lowered slowly until the water level inside and out coincides. The water contained in the bottle is then measured, and the difference between this and the total capacity of the bottle is equal to the nitrogen.

709. There are many other forms of gas analysis apparatus; the principles governing the use of same are similar to those described in this chapter.

Furnace Gases.

710. The economical working of the furnaces in a gas works is of great importance, and the analysis of the generator and spent gases should be made in order that the proper amount of air should be supplied for the complete combustion of the carbon monoxide contained in the generator gases.

711. *Generator gas* should theoretically consist of about 35 per cent. of carbon monoxide (CO) and 65 per cent. nitrogen. As a matter of fact, this is not generally obtained in working, but a generator gas, on analysis, should contain about 30 per cent. of carbon monoxide (CO), while the amount of carbon dioxide (CO_2) should not exceed 5 to 6 per cent.

712. *Spent gas*, on the other hand, should contain prac-

tically no carbon monoxide (CO), very little oxygen, and if combustion is perfect, 21 per cent. of carbon dioxide (CO₂), the remainder being nitrogen. The "rule of thumb" method, by which a workman knows if his furnaces are going badly, is that when the CO burns with a blue flame at the top of the stack he knows the supply of air requires regulation and he strives to get rid of the flame, or in other words, to eliminate the CO.

713. It will, therefore, be seen that generator gases and spent gases should be analysed for percentages of CO₂, O and CO, while a useful check upon the working is ascertained by an apparatus by which the amount of CO₂ found in the spent gases is indicated, as Craig's combustion tester.

714. *Orsat-Muencke's* apparatus is much used for the analysis of these gases. It is made in many modified forms, most of which have for their object the simplification of working and the utilisation of mercury as the containing fluid.

715. The apparatus, Fig. 84, is mounted in a wooden case with removable back and front, so that it can be carried about a works and tests made at any point.

It consists of a measuring burette having a capacity of 100 cubic centimetres, and surrounded by a water-jacket. The burette is connected at its base with the bottle which contains water, brine, or preferably mercury, and by means of which the level in the burette is raised or lowered, so that the gases are measured at atmospheric pressure. The top of the burette communicates by means of thick-walled, narrow bore capillary tube with three absorption vessels, the inlet to each being regulated by a cock and the outlet being connected with a relief vessel furnished with a tubulated exit, which can be connected to a bladder or other means of keeping out the air and driving back the reagent, if necessary. The series of capillary tubes is furnished with a cock, and

when this is opened and the other cocks closed the sample of gas is drawn into the burette for measurement.

716. The first vessel contains caustic potash solution, the second potassium pyrogallate, and the third acid solution of cuprous chloride. The absorbing vessels are filled with fine tubes placed vertically, so as to present a large surface

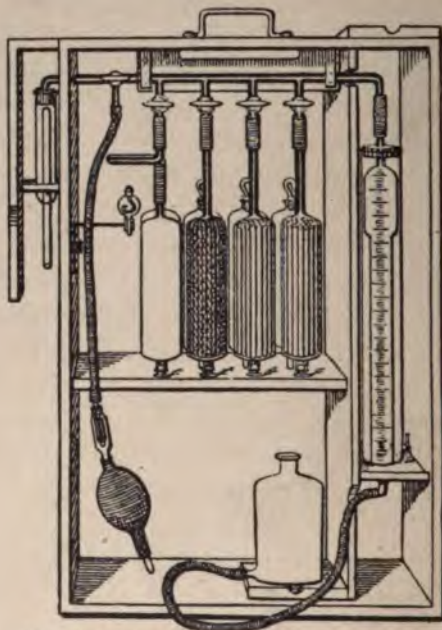


FIG. 84.—ORSAT-MUENCKE'S APPARATUS.

of reagent to the gas. The tubes in the cuprous chloride vessel contain pieces of copper wire, so as to keep the solution in a cuprous state. As these tubes are with advantage replaced from time to time, this third absorbing vessel is made with a removable top, soundness being secured by a ground joint. The gas is passed first into vessel No. 1 for absorption of CO_2 , and is then transferred to the burette and measured; secondly, to vessel No. 2 for absorption of O, and then

measured; thirdly, to vessel No. 3 for absorption of CO , then into vessel No. 1 for extraction of acid vapours before

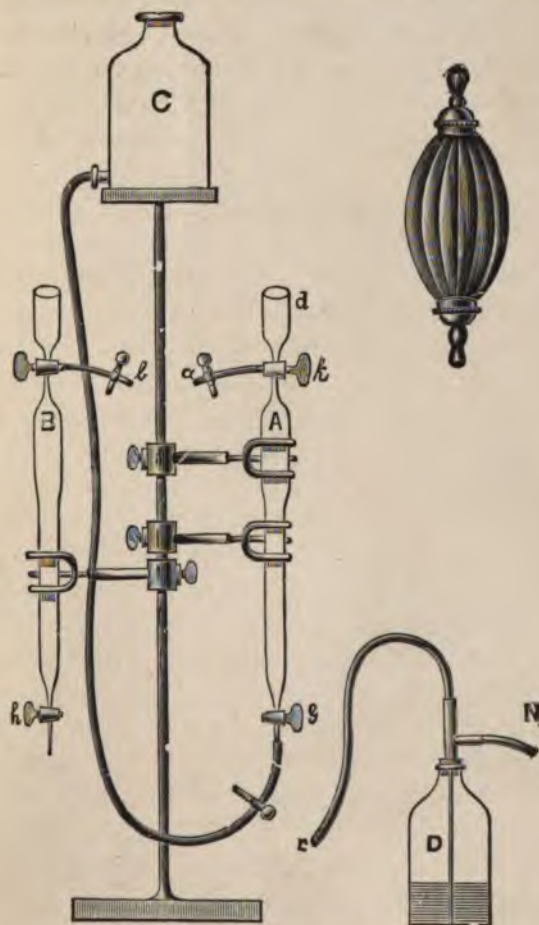


FIG. 85.—BUNTE'S APPARATUS.

being measured. The gas is passed from the burette to the vessels, and *vice versa*, by raising and lowering the bottle containing water, brine or mercury. Some of the better-

known modifications consist of the provision of one cock communicating in turn to the three vessels, instead of the three cocks; the provision of a companion-tube to the burette, by means of which the equality of level of mercury in bottle and burette can be the better ascertained; the provision of a correction-tube (as in Hempel's burette already described) and having also for its object the facilitating of the use of mercury.

717. *Bunte's burette* is another simple instrument, by means of which furnace gases can be analysed. The apparatus in an improved form is illustrated in Fig. 85, and the instructions for working are as follows:

718. Referring to the illustration, *A* and *B* are two burettes of a capacity of about 110 cubic centimetres each; graduated from zero to 100 upwards, and about 10 cubic centimetres below the zero mark, the graduations being 0.2 of a cubic centimetre. Each burette is furnished with a three-way stop-cock having a stem exit from burette, and is surmounted by a funnel *d*, with a mark engraved at about 25 cubic centimetres. The burettes terminate with a stop-cock (*g*, *h*), below which is a capillary tube for attachment to rubber tube. *C* is a one-gallon water bottle, and *D* is a suction bottle.

719. The gas is drawn from the flue or furnace through a porcelain- or platinum-lined tube, which is thrust into the flue, and which serves as a means of transferring the gas to be analysed into a suitable vessel. The entrance of the pipe to the flue must be plugged, and every precaution taken that no air is drawn in with the gas.

720. The burette *A* is filled with water from the bottle *C*, the funnel *D* being also nearly filled, and *k* being turned off when all air has been expelled. The rubber tube from *C* is then clamped and disconnected and the suction-bottle *D* connected in its place. A tube conveying gas is connected

to stem exit *a* of cock *k*, and by opening the way from *a* to *A*, and also cock *g*, the water flows from the burette, being followed by gas, until nearly all the water has run out. Bottle *D* is then disconnected and *C* connected up; water is allowed to enter until the graduation of, say, 5 is reached; the gas being thus compressed, water is allowed to run out carefully until the zero is reached, when *g* is closed and *k* is carefully opened, allowing gas to bubble through the water in the funnel, which is maintained at a uniform level through the test, until exactly 100 cubic centimetres are contained in the burette, at normal atmospheric pressure. In taking the measurement at this and subsequent stages it is necessary to remember what has been before stated as to the importance of securing constant temperature and pressure. In this case this can be easily secured (as the burette can be easily removed from its stand) by the provision of a tin vessel about 8" diameter (wider at the top) and 4 feet high, filled with water. Into this the burette can be plunged before readings are taken, thus securing constancy of temperature.

721. CO_2 .—The first analysis made is that for carbon dioxide. The solution used as a reagent is as before, caustic potash KHO. The method of procedure is as follows: The burette *A* contains 100 cubic centimetres of gas, with water below it. Connect bottom of burette with the suction bottle *D*, apply suction at *N*, carefully opening the cock *g*, and drawing out nearly all the water. Then close cock *g* and remove the suction-bottle. Place some KHO in a porcelain basin, dip the capillary of burette into it, open cock *g*, and the KHO will flow up to replace the water; then close cock *g*. Take burette from its stand and shake well, placing the hand firmly on *d*, and being careful not to handle body of burette more than is necessary. If the absorption is found not to be complete apply more KHO and repeat operation. The stop-cock *k* is then opened and water allowed to flow until it

ceases, care being taken not to unseal at *k*; when water has ceased to flow the cock *k* is closed and the residual gas is at atmospheric pressure as before, and the burette is plunged into the water-tank, so as to reduce to same temperature as before. The reduction in volume of gas is amount absorbed by KHO, and the percentage of CO_2 is thus read off burette.

O.—The determination of oxygen is then proceeded with as before, first drawing off the KHO and using potassium pyrogallate (observing the usual precautions as to oxidation.) If oxygen is present the solution turns dark red or black if a large amount of O is present. The reading is taken as before.

CO.—The carbon monoxide which would be present if a generator gas were being analysed may be estimated by an HCl solution of cuprous chloride applied like the other reagents—following same, however, with KHO to absorb acid vapours and then measuring reduction as before.

722. It is frequently the custom to estimate carbon monoxide (CO) and hydrogen by combustion with heated palladium wire. Expel part of the gas until a known portion of the original sample remains, say, 30 cubic centimetres. Open cock *k*, and allow, say, 50 cubic centimetres of air to enter burette. Ascertain the volume of the mixture after establishing atmospheric pressure as before. Connect the stem exit *a* of burette *A* to stem exit *b* of burette *B*, inserting in the passage or connection a piece of glass tube containing palladium wire or a piece of palladium tube. Burette *B*, being filled with water, the palladium is heated by a Bunsen burner, and the bottom of burette *B* being connected to bottle *C*, the gas is passed from *A* to *B*, replacing the water which runs out of the latter. The gas is then passed back to *A*, reduced as before to normal temperature and pressure, and amount read off and noted.

723. What has taken place is this: The CO has united

(in the presence of the heated palladium) with O of air forming CO_2 , and causing a reduction in the volume equal to the amount of CO_2 formed, which is found by KHO as before. The H has united (in the presence of the heated palladium) with O of air, forming H_2O and causing a reduction in the volume equal to two-thirds of the total contraction, less that due to half the volume of CO found, as the CO must have united with half its volume of O. The difference found is nitrogen. If only H and N were present, as in a waste gas, the amount of H is represented by two-thirds the reduction, since for every 3 volumes contracted by formation of H_2O two are H and one O.

724. Assume a *waste gas* were under examination and that the percentage previously found of CO_2 showed the practical absence of CO, and it were desired to ascertain amount of H and N. Suppose 76 cubic centimetres of gas were left in burette after examination of CO_2 and O, the percentages of which aggregated 24. Then, if we take 38 cubic centimetres of this, we shall be dealing with the equivalent of half the 100 cubic centimetres originally taken. Suppose this 38 cubic centimetres to be passed over the palladium after being made up to 85 cubic centimetres with air. Suppose after combustion of this 85 cubic centimetres there remained 76 cubic centimetres. The contraction is thus equal to 9 cubic centimetres, of which two-thirds is due to H and remainder to N.

Then $\frac{3}{2} \times 9 = 6$ c.c. H, and $6 \text{ c.c.} \times 2 = 12\% \text{ hydrogen,}$

and the CO_2 and O amount to 24%.

Therefore $N = 100 - (12 + 24) = 64\% \text{ nitrogen.}$

725. Assume a *generator gas* were under examination, and that after absorption of CO_2 and O there remained 90 cubic centimetres of gas in the burette. Then, if we take 30 cubic centimetres of this, we shall be dealing with the

equivalent of one-third the 100 cubic centimetres originally taken. Suppose this were mixed with 50 cubic centimetres of air, making up to 80 cubic centimetres, and that after combustion of this 80 cubic centimetres there remained 71 cubic centimetres. The contraction is thus equal to 9 cubic centimetres. Upon the 71 cubic centimetres being subjected to reaction with KHO the CO_2 formed from combustion of the CO will be indicated and thus the percentage of CO found. Suppose the KHO to absorb 7 cubic centimetres; the 7 cubic centimetres of CO were present in the 30 cubic centimetres of gas taken, and the percentage of CO = $7 \text{ c.c.} \times 3 = 21 \text{ per cent. carbon monoxide}$. Now the CO would have combined with half its volume of O, therefore $7 \div 2 = 3.5$ volumes of the contraction would have been due to CO. The contraction was 9 c.c., and $9 \text{ c.c.} - 3.5 \text{ c.c.} = 5.5 \text{ c.c.}$ As before stated, two-thirds of this is due to hydrogen:

$$\therefore \text{H} = \frac{5.5 \times 2}{3} = 3 \frac{2}{3} \text{ c.c., and } 3 \frac{2}{3} \times 3 = 11\% \text{ hydrogen.}$$

The remainder is nitrogen, thus:

$$30 \text{ c.c.} - (7 \text{ c.c.} + 3 \frac{2}{3} \text{ c.c.}) = 19 \frac{1}{3} \text{ c.c., or } 58\% \text{ nitrogen.}$$

726. When analysing generator or furnace gases it often happens that after the absorption of the absorbable constituents the combustible gas remaining in the residue is so small that it will not explode when mixed with air and sparked (this is on account of the presence of a large amount of nitrogen). Hydrogen gas is, therefore, added (from a hydrogen-generator pipette) to the portion of the residue taken for explosion. The following is an example:

The absorbable constituents gave the following results:

Carbon dioxide	4.0 per cent.
Oxygen	0.8 "
Carbon monoxide	24.0 "

and the residual gas amounted to 71.2 c.cm. A portion of this residue was mixed with air and hydrogen, in the following proportions:

Gas residue taken	= 14.5 c.cm.
Air "	= 76.0 "
Hydrogen "	= 9.0 "
Total	= 99.5 "

This mixture was exploded, and after the explosion the volume was found to be 81.7 cubic centimetres. The total contraction was, therefore, $99.5 - 81.7 = 17.8$ cubic centimetres. The 9.0 cubic centimetres of hydrogen added to the gas residue, used, during its combustion, one-half its volume of oxygen ($= 4.5$ c.c.), so that the contraction due to this ($9 + 4.5$ c.c., or 13.5 c.c.) must be deducted from the total contraction (17.8 c.c.) in order to determine the contraction due to the hydrogen and methane contained as constituents in the generator gas. Therefore, $17.8 - 13.5 = 4.3$ c.c. contraction. The carbon dioxide formed during the combustion (ascertained by absorption with KHO as before) amounted to 0.9 c.c., which is equivalent to the amount of methane contained in the residue taken for explosion.

Methane.—The amount of methane in the total gas residue will be:

$$\frac{71.2 \text{ c.c.} \times 0.9 \text{ c.c.}}{14.5 \text{ c.c.}} = 4.4 \text{ per cent. methane.}$$

Hydrogen.—As stated previously, the amount of hydrogen is calculated by subtracting twice the volume of the carbon dioxide found from the contraction, and then multiplying that result by $\frac{2}{3}$.

Therefore, $[4.3 - (0.9 \times 2)] \times \frac{2}{3} = 1.67$ c.c. of hydrogen.

And the amount of hydrogen in the total gas residue will be:

$$\frac{71.2 \text{ c.c.} \times 1.67 \text{ c.c.}}{14.5 \text{ c.c.}} = 8.2 \text{ per cent. of hydrogen.}$$

Nitrogen.—This gas is found by difference.
The Generator gas contained the following:

Carbon dioxide	=	4.0	per cent.
Oxygen	=	0.8	"
Carbon monoxide	=	24.0	"
Methane	=	4.4	"
Hydrogen	=	8.2	"
Nitrogen (by diff.)	=	58.6	"

NOTE.—Hempel directs that where the *H* is determined by

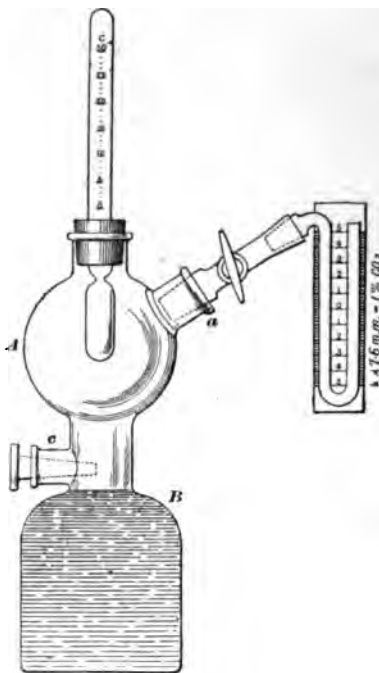


FIG. 86.—OECHELHAUSER'S CO₂ APPARATUS.

palladium (after the absorption of CO), the CO should be absorbed by the *ammoniacal* and not the *acid solution* of cuprous chloride.

727. A rapid method of estimating the percentage of CO_2 in furnace gas is furnished by Oechelhauser's apparatus, illustrated in Fig. 86 and described below :

The vessel *B* is charged with a solution consisting of 0.5 ounce or 16 grains of caustic potash or caustic soda dissolved in enough distilled water to fill it to the middle of *C*. The gas is then forced or drawn through the upper bulb *A* from (*c*) to (*a*) until a good sample is secured. Both these openings are then closed, the whole apparatus

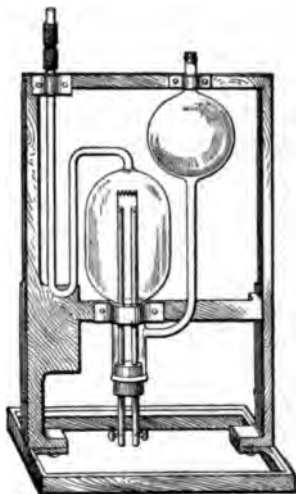


FIG. 86a.—SLOW COMBUSTION PIPETTE.

inverted a few times, placed on a table and the syphon gauge attached, from which the percentage of carbon dioxide can be directly read. If the temperatures before and after the absorption differ, 0.33 per cent. must be added or subtracted for every degree of increase or decrease of temperature, respectively.

The apparatus was brought to the writer's notice by a paper communicated by W. E. Steinwedell to the meeting held in May, 1901, of the Western Gas Association (U. S. A.).

728. An illustration has been given in Fig. 81 of a pipette

used for combustion of residual gas by sparking and the method has been described. An alternative method by combustion over palladium is also referred to in paragraph 722 *et seq.* There is yet another method by which the residual gas can be analysed, and the pipette is illustrated in Fig. 86a. The difference consists of the fact that in this apparatus the gas, with admixture of oxygen (or hydrogen also if required) is not exploded, but slowly burnt to CO_2 and water in the presence of a red-hot wire connecting the terminals inside the pipette.

[NOTE.—Pars. 729-750 are left blank to facilitate additions in a future edition.]

CHAPTER XI.

METER-TESTING APPARATUS.

The following two chapters, which deal with Gas Meter Testing under the "Sales of Gas" Acts, are arranged as follows:

Chap. XI.	
Paragraphs.	
751 to 762	General Information as to the Acts.
763 to 766	Methods of Graduating the Standard Measures.
767 to 780	Standard Test Gas Holders.
781 to 791	Standard Test Gas Meters.
792 to 798	Description of a Testing Station.
Chap. XII.	
Paragraphs.	
799 to 815	Meters to be Tested Officially.
816 to 838	Testing by Holder Officially.
839 to 849	Testing by Meter Officially.
850 to 851	Suggested Amendment of Acts.
852 to 854	Information as to Books, Forms, etc.
855 to 867	Meter and Governor Testing at a Gas Works.

751. It is a remarkable fact in the history of gas-lighting in this country, that although gas companies at the outset adopted the cubic foot as the unit for gas measurement, and, when meters were introduced, actually sold gas under the authority of their respective Acts of Parliament at rates due to a 1000 or 100 cubic feet, there should have been no cubic foot measure or any gas measure included among the standard measures of the nation, and that gas measures of all kinds, inclusive of gas meters, should have remained until

the year 1861 altogether exempt from any such examination and verification by public officials, as all other measures of capacity, etc., were subjected to by law.

752. Notwithstanding the non-existence of an official standard measure of the capacity of a cubic foot, the weight of water equal in bulk to a cubic foot had been determined, and consequently water had been used in various ways down to the year 1861 as an agent for ascertaining the capacity of, and for graduating instruments to be used, for measuring gas.

753. Previous to the year 1861 many, if not most, persons who were concerned in making gas measures adopted 62.5 pounds as the weight of water equal to the bulk of a cubic foot, although it was known that Kater's experiments showed that at 62° Fahr., and with the barometer at 30 inches, the weight of a cubic foot of pure distilled water weighed in air was 62.321 pounds avoirdupois. Ordinary water, which is denser than distilled water, was, however, usually employed by the makers of measures; but then no care was taken to free it from air by boiling before use, so that the greater density which would diminish the bulk of 62.5 pounds was, to an uncertain extent, compensated for by the presence of air, which would lessen the specific gravity of the water. So that when measurement was effected by the aid of water actually weighed under normal conditions, there existed no reason for grave differences in the derived measures of various makers. There can be little doubt, however, that some operators when using and weighing water were indifferent alike to its temperature and to atmospheric pressure, and were, it may be, still less regardful in respect to equality in the temperature of both air and water when graduating gas measures. Another source of difference was that while some determined cubic capacity by weighing the water, others did so by measuring the water.

Certain it is that from various causes test-gasholders differed to an important extent from each other in capacity throughout the kingdom, although it might be that in a particular district test-gasholders closely agreed with each other.

754. In the year 1859 an Act was passed entitled "An Act for Regulating Measures Used in Sales of Gas." This Act was modified by two subsequent Acts, which deferred the date at which it was to come into operation, changed some of the authorities who were to carry its provisions into execution, and finally rendered its application permissive instead of compulsory—dependent, in fact, upon the resolutions of magistrates and other local authorities. As a consequence of the last alteration many of the authorities neglected to adopt the Act from considerations, it may be, of the attendant expenses. Nevertheless, the Act is virtually in operation all over the kingdom, for no meters are put into use without having been previously verified and stamped by a Public Inspector. The Acts regulating the sales of gas—so far as supply by meter and meter-testing are concerned—are four in number, viz.:

"The Sales of Gas Act, 1859, 22 and 23 Vict., Cap. 66."

"The Sales of Gas Amendment Act, 1860, 23 and 24 Vict., Cap. 146."

"Sales of Gas (Scotland) Act, 1864, 27 and 28 Vict., Cap. 96."

"Metropolis Gas Act Amendment Act, 24 and 25 Vict., Cap. 79."

The first two are important and are set forth below *in extenso*. The "Scotland" Act makes the "Sales of Gas Act" apply to Scotland, while the "Metropolis Gas Act Amendment Act" renders compulsory for the metropolis certain clauses in the "Sales of Gas Amendment Act" which are only permissive elsewhere.

SALES OF GAS ACT.

755. AN ACT FOR REGULATING MEASURES USED IN
SALES OF GAS. [13th August, 1859.]

Whereas it is expedient that the Measurement used in Sales of Gas for Lighting, Heating, and other Purposes should be hereafter regulated by One uniform Standard, and that all Meters should be stamped as hereinafter provided: Be it therefore enacted by the Queen's most Excellent Majesty, by and with the Advice and Consent of the Lords Spiritual and Temporal, and Commons, in this present Parliament assembled, and by the Authority of the same, as follows:

I. In construing this Act the Word "Meter" shall mean Gas Meter, and shall include every Kind of Machine used for measuring Gas; and the Word "Person" shall include Corporations.

II. After the passing of this Act the only legal Standard or Unit of Measure for the Sale of Gas by Meter shall be the Cubic Foot containing 62.321 Pounds Avoirdupois Weight of distilled or Rain Water weighed in Air at the Temperature of Sixty-two Degrees of Fahrenheit's Thermometer, the Barometer being at Thirty Inches, except as relates to Contracts made before the passing of this Act by which a different Unit of Measure is adopted, which Contracts may not be renewed.

III. Within Three Months next after the passing of this Act Models of Gasholders measuring the said Cubic Foot, and such Multiples and Decimal Parts of the said Cubic Foot as the Lord High Treasurer or the Commissioners of Her Majesty's Treasury of the United Kingdom for the Time being shall judge expedient, and from Time to Time after the Expiration of the aforesaid Period of Three Months Models of such further Multiples and Decimal Parts of the said Cubic Foot as the Lord High Treasurer or the Commissioners of Her Majesty's Treasury of the United Kingdom for the Time being shall judge expedient, and from Time to Time after the Expiration of the aforesaid Period of Three Months Models of such further Multiples and Decimal Parts of the said Cubic Foot as the Lord High Treasurer or the said Commissioners shall from Time to Time think expedient, shall be carefully made, with proper

Balances, Indices, and Apparatus, for testing the Measurement and Registration of Meters, and such Models shall be verified under the direction of the Lord High Treasurer or the said Commissioners, and when so made and verified shall be deposited in the Office of the Comptroller General of the Exchequer at *Westminster*; and Copies of the Models so from Time to Time deposited, verified as aforesaid, shall be sent to the Lord Mayor of *London*, and the Chief Magistrate of *Edinburgh* and *Dublin*, and to the Chief Magistrate of such other Cities and Boroughs, and to such other Places and Persons in Her Majesty's Dominions, as the said Lord High Treasurer or the aforesaid Commissioners may from Time to Time direct; and the said Lord High Treasurer or the said Commissioners shall appoint a competent Person or Persons to design and make, subject to the Approval and by Direction of such Lord High Treasurer or the said Commissioners, Stamps of a uniform Design to be used for Stamping Meters throughout the United Kingdom, with only such Variations of Numbers or Marks thereon as shall be sufficient to distinguish each Inspector's District.

IV. In *England* at some General or Quarter Sessions of the Peace within Nine Months next after the passing of this Act the Justices of the Peace of every County, Riding, or Division, or County of a City or County of a Town, in General or Quarter Sessions assembled, and in such Boroughs as may adopt this Act, as herein-after provided, the Town Council at the Meeting next after such Adoption, and in *Scotland* the Justices of the Peace at a Meeting to be called for the Purpose by the Sheriff of each County, and the Magistrates of each Royal Burgh, within Nine Months after the passing of this Act, and so from Time to Time at any subsequent General or Quarter Sessions or Meeting so called, shall determine the Number of Copies of the said Models of Gasholders, with proper Balances, Indices, and Apparatus as aforesaid, which they shall deem requisite for the testing of Meters within their respective Jurisdictions, and shall direct that such Copies, verified and stamped at the Exchequer, together with such Number of Stamps for stamping Meters as they shall deem requisite, shall be provided for the Use of the same, and shall fix the Places at which such Copies and Stamps shall be deposited, and shall appoint a sufficient Number of Inspectors of Meters for the safe

Custody of such Copies and Stamps, and for the Discharge of the other Duties hereinafter mentioned, and shall allot to each Inspector a separate District, and from Time to Time, when necessary, shall subdivide and reallot such Districts, and all such Districts shall be distinguished by the Number or Mark applied thereto on such Stamps, and they shall direct what reasonable Remuneration shall be paid to such Inspectors for the Discharge of such Duties as they shall have been ordered by such Justices or Town Council or Magistrates as aforesaid to perform, and they are hereby empowered to suspend or dismiss any Inspectors so appointed, or to appoint additional Inspectors as Occasion may require: Provided always, that nothing herein contained shall extend to compel any Town Council in *England* or Royal Burgh of *Scotland*, except such as are County Towns, wherein Gas is used, to provide Copies of the said Models and Stamps, or to appoint an Inspector or Inspectors for the Performance of the Duties prescribed by this Act; and that it shall be lawful for the Justices of the Peace in any County, and for the Magistrates of any Royal Burgh within such County, where they shall agree, to unite the whole or a Portion of the County with such Royal Burgh, and to appoint One Inspector therefor, and to provide at their joint Expense Copies of the said Models and Stamps to be used within such united Districts: Provided always, that in every Borough in *England* where there is a Town Council, not being a Manufacturer or Seller of Gas, it shall be lawful for such Town Council within Six Months after the passing of this Act, after One Month's Notice duly given in the Manner in which Notices are usually published by such Town Council, to adopt this Act, if the Majority of the Members present at any Council Meeting at which the Subject is appointed to be considered shall so determine; and if no Resolution to that Effect shall be passed within such Time, then the Justices aforesaid, at their next practicable General or Quarter Sessions after the Expiration of such Six Months, shall in reference to any Borough not so adopting this Act carry this Act into effect; and in all Boroughs as aforesaid in which the Town Council is a Manufacturer or Seller of Gas, the Justices of such Boroughs shall have such and the like Powers of adopting and carrying into effect the Provisions of this Act within such Boroughs as by this Act are given

to Town Councils not being Manufacturers or Sellers of Gas.

V. In *Ireland* the Town Council or Town Commissioners of every Borough and Town, such Town Council or Commissioners not being Manufacturers or Sellers of Gas, shall at a meeting of the Town Council or Commissioners to be held within Nine Months after the passing of this Act, and so from Time to Time at any subsequent Meeting, determine the Number of Copies of the said Models of Gasholders, with proper Balances, Indices, and Apparatus as aforesaid, which they shall deem requisite for the testing of Meters within their Towns or Boroughs respectively, and shall direct that such Copies, verified and stamped at the Exchequer, together with such Number of Stamps for Stamping Meters as they shall deem requisite, shall be provided for the Use of the same, and shall fix the Places at which such Copies and Stamps shall be deposited, and shall appoint a sufficient Number of Inspectors of Meters for the safe Custody of such Copies and Stamps, and for the Discharge of the other Duties hereinafter mentioned, and shall allot to each Inspector a separate District, and from Time to Time, when necessary, shall subdivide and re-allot such Districts, and shall direct what reasonable Remuneration shall be paid to such Inspectors, and they are hereby empowered to suspend or dismiss any Inspector so appointed, or to appoint additional Inspectors from Time to Time as Occasion may require; and in all Boroughs and Towns in which the Town Council or Town Commissioners shall be Manufacturers or Sellers of Gas, the Justices of such Boroughs and the Grand Jury of the County in which such Boroughs or Towns not having a separate Commission of the Peace shall be situate respectively shall have such and the like Powers as by this Act are given to the Town Council and Town Commissioners not being Manufacturers or Sellers of Gas for carrying into effect the Provisions of this Act within such Boroughs and Towns: Provided always, that the Jurisdictions of such Town Council and Town Commissioners, Justices, and Grand Juries respectively shall extend to all Meters out of such Boroughs or Towns for measuring Gas manufactured at any Gasworks by which any such Borough or Town shall be supplied with Gas.

VI. The Copies of the said Models so directed by the

said Justices, Magistrates, or Town Council to be verified and stamped at the Exchequer shall be compared with the Models deposited with the Comptroller General of the Exchequer as aforesaid, and if correct shall be verified and stamped by the Comptroller General, or some other Officer of the Exchequer at *Westminster*, duly authorized, upon Payment of such Fees as are at present payable upon Verification and stamping a Set of Measures under the Acts relating to weights and Measures, and no Stamp Duty shall be payable thereon.

VII. The Expense of providing and transmitting such Copies of Models of Gasholders, with proper Balances, Indices, and Apparatus as aforesaid, and of the Stamp to be used by the Inspectors, and the Remuneration to the Inspectors, shall be paid in *England* out of the Stock raised in such Counties, Ridings, Divisions, Counties of Cities or Counties of Towns, and in Boroughs out of any Funds applicable to Lighting Purposes, and if no such Funds then out of the Borough Fund; and in *Scotland* such Expenses in the respective Shires and Stewartries, and Cities or Royal Burghs, shall be assessed by the Commissioners of Supply upon such Shires and Stewartries, and upon Cities or Royal Burghs by the Magistrates thereof, according to the Real Rent of Lands and Heritages as appearing on the Valuation Roll of such Shires, Stewartries, and Burghs respectively, and in such Manner and by such Persons as the said Commissioners of Supply and Magistrates respectively may determine and appoint, and such Assessments shall be collected under the same Powers of levying and Recovery as are competent for levying and recovering the Land Tax; Provided always, that in the City of *London* the Expenses and Remuneration aforesaid shall be paid out of the Consolidated Rate raised by the Commissioners of Sewers of the City of *London*, and in *Ireland* such Expenses in the respective Boroughs and Towns shall be provided for and paid respectively out of any Funds applicable to Lighting Purposes, and if no such Fund then out of any other Borough or Town Fund.

VIII. No Maker, Repairer, or Seller of Meters or of Gas, or Person employed in the making, repairing, or selling of Meters or Gas, shall be an Inspector of Meters under the Provisions of this act; and every Inspector shall forthwith enter into a Bond or Recognizance to the

Queen, to be sued for in any Courts of Record, in such Sum, and either with or without a Surety or Sureties, as the Justices, Magistrates, Town Council, or Other Persons by whom he may have been appointed shall fix, for the due and punctual Performance of the Duties of his Office, and for the due and punctual Payment at such Time or Times as he may be directed by the Justices, Magistrates, Town Council, or other Persons by whom he may have been appointed, of all Fees received by him under the Authority of this Act, and for the Safety of the said Copies of Models and Stamps committed to his Charge, and for their due Restoration and Surrender to such Person or Persons as may be appointed to receive them by the Justices, Magistrates, Town Council, or other Persons aforesaid immediately on his Removal or other Cessation from Office.

IX. In *England* the Justices in General or Quarter Sessions assembled, or the Town Council in Boroughs adopting this Act at any Meeting thereof, and in *Scotland* the Justices or Magistrates at a Meeting called for the Purpose, and in *Ireland* the Town Council or Town Commissioners of any Borough or Town as aforesaid, shall determine and appoint on what Days, and at what Hours, and what Places each and every Inspector shall attend with the said Copies of Models and Stamps in his Custody at each of the several Towns and Districts within their respective Jurisdictions as they shall deem expedient; and every such Inspector so attending shall examine, test, and, if found correct, stamp all such Meters as shall be required under the Provisions of this Act to be so examined, tested, and stamped, and shall deface or destroy the Stamp on any Meter tested and found incorrect under the Provisions of this Act, and he shall keep a Book wherein he shall enter Minutes of all such Examinations and Testings, with the Numbers of Identity and Capacity marked by the Manufacturer on such meters, and give, if required, a Certificate under his Hand of every such Stamping and Defacing; and every Inspector shall once in every Quarter of a Year account to the Treasurer of the County, Riding, Division, County of a City or County of a Town, or Borough or Town, or to such other Person as shall be duly authorised by those by whom he may have been appointed, for all Fees received by him under this Act, and shall pay the Amount thereof to such Treasurer as aforesaid, who shall account for the same.

X. No Meter duly stamped under the Authority of this Act shall be liable to be re-stamped, although the same be used in any other Place than that at which the same was originally stamped, but shall be considered as a legal Meter throughout the United Kingdom, unless found to be incorrect within the Meaning of this Act.

XI. In case any Inspector of Meters shall stamp any Meter without duly testing and finding the same to be correct, or shall refuse, or for Three Days after being so required under the Provisions of this Act neglect, without lawful Excuse, to test any Meter or to stamp any Meter found to be correct on being so tested, or shall be guilty of a Breach of any Duty imposed upon him by this Act, or shall otherwise misconduct himself in the Execution of his Office, every such Offender shall upon Conviction forfeit a Sum not exceeding Five Pounds for every such Offence.

XII. No Meter shall be stamped which shall be found by the Inspector to register, or be capable of being made by any Contrivance for that Purpose, or by Increase or by Decrease of the Water in such Meter, or by any other Means practically prevented in good Meters, to register, Quantities varying from the true Standard Measure of Gas more than Two *per Centum* in favour of the Seller or Three *per Centum* in favour of the Consumer; and every Meter, whether stamped or unstamped, which shall be found by such Inspector to register or be so capable of being made to register Quantities varying beyond the Limits aforesaid, shall be deemed incorrect within the Meaning of this Act; and every Meter which shall be found by such Inspector to measure and register Quantities accurately, or not varying beyond the Limits aforesaid, and shall be found incapable by any such Means as aforesaid of being made to register Quantities varying beyond the Limits aforesaid, shall be considered to be correct, and be stamped as aforesaid in such Manner and on such Part of the Meter as shall be specially directed by the Authority appointing him, or in default of such Direction as shall in his Opinion best prevent Fraud; Provided always, that every Meter having a measuring Capacity at One Revolution or complete Action of the Meter of not less than Five Cubic Feet, and having permanently marked upon it in some conspicuous Place the Words "without Float," shall be stamped by the Inspectors, if

found correct within the meaning of this Act, in all other respects except that it is capable of being made by Abstraction of Water to register incorrectly against the Seller of Gas, but it shall not be lawful after the Time aforesaid to use in the Sale of Gas any such Meter, when so stamped by the Inspector, except by written Agreement between the Buyer and Seller specifying that this Description of Meter shall be used.

XIII. The following rules shall be observed by the Inspector in testing Meters under the Provisions of this Act:

Firstly, the Meters shall be tested for Soundness or Leakage only, and not for Per-centage of Error, when fixed on a horizontal Base, and with Gas under a Pressure equal to a Column of Water Three Inches high, with a Light or Lights consuming not more than One-Twentieth Part of its measuring Capacity *per* Hour marked thereon, nor less than One-Half of a Cubic Foot *per* Hour, for all Meters of a measuring Capacity not exceeding One hundred Cubic Feet *per* Hour, and not more than One Fortieth Part of its said measuring Capacity *per* Hour for all Meters of any greater measuring Capacity *per* Hour than One hundred Cubic Feet; and all Meters found to work under such Test shall be deemed sound Meters, and any Meter found not to work under such Test shall not be stamped:

The Meter to be tested for Per-centage of Error shall be fixed on a horizontal Base, and shall be tested at a Pressure equal to a Column of Water Five-Tenths of an Inch high, and passing the Quantity of Gas or Atmospheric Air *per* Hour which shall be marked thereon as its measuring Capacity *per* Hour, and the Water used in such Testing, and the Air of the Room in which such Testing shall be made shall be as nearly as practicable of the same Temperature as the Gas or Air passed through the Meter.

XIV. If any Person or Persons shall make, except under the Authority of this Act, or forge or counterfeit, or cause or procure to be made, except as aforesaid, or forged or counterfeited, or knowingly act or assist in the making, except as aforesaid, or forging or counterfeiting, any Stamp or Mark which may hereafter be used for the stamping or marking of any Meter under this Act, every Person so offending shall for every such Offence forfeit on Conviction a Sum not exceeding Fifty Pounds or less

than Ten Pounds; and if any Person shall knowingly sell, utter, or dispose of, let, lend, or expose to Sale, any Meter with such forged stamp or Mark thereon, every Person so offending shall for every such Offence forfeit on Conviction a Sum not exceeding Ten Pounds or less than Forty Shilings, and all Meters with such forged or counterfeited Stamps shall be forfeited and destroyed.

XV. Any Person who shall knowingly repair or alter, or knowingly cause to be repaired or altered, or knowingly tamper with, or do any other Act in relation to any stamped Meter so as to cause such Meter to register unjustly or fraudulently, or who shall prevent or refuse to allow lawful Access to any Meter in his Possession or Control, or the Supply of Water thereto as herein-after provided, or shall obstruct or hinder any Examination or Testing authorised by this Act of any such Meter, shall on Conviction forfeit a Sum not exceeding Five Pounds, pay the Fees for removing and testing, and the Expense of purchasing and fixing a new Meter; provided that the Payment of any such Penalty as aforesaid shall not exempt the Person paying from Liability to Indictment or other Proceeding at Law to which he would otherwise be liable, or deprive any Person of the Right to recover Damages against such Person for any Loss or Injury sustained by such Act or Default.

XVI. Every consumer of Gas may purchase and use for the Measurement of the Gas supplied to him any Meter duly stamped under the Authority of this Act, provided that the Gas to be consumed *per* Hour shall not exceed the Quantity *per* Hour the Meter is intended to measure, so marked on the Outside thereof as aforesaid.

XVII. After the Expiration of Ten Years from the passing of this Act all Meters whatsoever not previously stamped which shall be used for buying and selling Gas, or for the collecting of any Rates or Duties, or for making any Charges on the Passage, Transmission, or Conveyance of Gas, shall be examined and tested under the Authority of this Act, and stamped if found correct; and every Person who shall after the Times respectively fixed by this Act knowingly use any Meter which has not been so stamped as aforesaid shall on Conviction forfeit a Sum not exceeding Five Pounds, and any Contract, Bargain, or Sale made by any such Meter shall be void; and every such meter so used shall, on being discovered by any In-

specter so appointed as aforesaid, be seized, and, on Conviction of the Person knowingly using or possessing the same, shall be forfeited and destroyed.

XVIII. No Meter for the Purpose of ascertaining the Quantity of Gas sold shall be fixed for Use after the Expiration of Twelve Months after the passing of this Act, unless the same shall have its measuring Capacity at One Revolution or complete Action of the Meter, and also the Quantity *per* Hour it is intended to measure in Cubic Feet, or Multiples or Decimal Parts of a Cubic Foot, denominated or marked on the Outside thereof in legible Letters or Figures, and shall be stamped by an Inspector of Meters under the Provisions of this Act; and every Person who after the Expiration of such Twelve Months shall fix for Use any such Meter before it has been so stamped shall be liable to a Penalty of Five Pounds for every such unstamped Meter; and all Meters required to be tested and stamped, except as herein-after mentioned, shall be delivered to the Inspector at the Place where his testing Gasholder and Apparatus may be kept; and every Purchaser and Seller of Gas by Meter may, at his own Expense, at any Time after the Expiration of the said Twelve Months, require any unstamped Meter by which his Gas is measured to be examined, tested, and, if found correct, stamped, or he may at his own Expense substitute a stamped Meter in the Place of any such unstamped Meter: Provided always, that such Purchaser or Seller of Gas shall before Removal of any such unstamped Meter for the Purposes aforesaid give Twenty-four Hours' Notice in Writing of such intended Removal to the other Party to the Contract.

XIX. The Fees for Examination, Comparison, and testing, with or without stamping, Meters, shall be Sixpence for each Meter delivering a cubic Foot of Gas in Four or more Revolutions or complete Repetitions of the Action of the Meter, and One Shilling for each Meter delivering a Cubic Foot of Gas by any less Number of Revolutions or complete Actions, or One Revolution or complete Action, and for each Meter delivering more than One Cubic Foot of Gas by One Revolution or complete Action the further sum of One Shilling for every Cubic Foot of Gas delivered at One Revolution or complete Action beyond the First Cubic Foot.

XX. In *England* and in such Boroughs and Towns as

aforesaid in *Ireland* it shall be lawful for any Inspector authorised in Writing under the Hand of any Justice of the Peace in *England* or *Ireland*, or of any Sheriff, Justice, or Magistrate in *Scotland*, at the Request and Expense of any Buyer or Seller of Gas, who shall have given Twenty-four Hours' Notice in Writing to the other Party to the Contract, at all seasonable Times to enter any House or Shop, Store, Warehouse, Still, Yard, or Place whatsoever within his Jurisdiction where any Meter, whether stamped or unstamped, shall be fixed or used, and to examine and test the same, and if necessary for such Purpose to remove such Meter, doing as little Damage thereby as may be; and if upon such Examination and Testing it shall appear that any such Meter is incorrect within the Meaning of this Act, or fraudulent, the same shall not be refixed or used again unless and until altered and repaired so as to measure and register correctly, and stamped; and the Fees on such removal, Examination, and Testing of a Meter, whether stamped and replaced or not, shall be double the Fees herein-before made payable for testing and stamping, and shall be payable to the Buyer or Seller of Gas as the Justice of the Peace in *England* or *Ireland*, or the Sheriff, Justice, or Magistrate in *Scotland*, as the case may be, shall determine, and shall be recoverable accordingly: Provided always, that in case the Head Office of the Person or Company to whom such Notice is to be given shall be more than Twenty Miles distant from the Meter referred to in such Notice, Three Days' Notice in Writing shall be given instead of Twenty-four Hours' Notice as aforesaid; and provided also, that any Person duly authorised by any Company or Persons selling Gas by Meter may supply Water to any Meter, so as to keep the Water at the correct Level.

XXI. In case of any Dispute between the Buyer and Seller of Gas by Meter, or between any Owner of a Meter and any Inspector of Meters under this Act, respecting the Correctness of any Meter, the Inspector shall, if required by any such Person dissatisfied with his Decision, give such Party his Reasons in Writing for such Decision, and such Party may require such Meter to be examined and re-tested by two Inspectors of adjoining or neighbouring Districts, to be named by any Justice of the Peace having Jurisdiction in the District where such Meter shall have been tested; and the unanimous Decision of such last-

mentioned Inspectors shall be final as to the Correctness or Incorrectness of such Meter, except in case of Appeal to the General or Quarter Sessions; and in case such Two Inspectors shall not agree, the Decision of the Inspector of the District to which such Meter belongs shall be considered final, except in case of Appeal to the General or Quarter Sessions, as hereinafter provided; and the Expenses of the Proceedings to be taken under the Powers hereby granted shall be ascertained by the Justice, who shall also determine by and to whom the same shall be paid, and such Expenses shall be recovered in any Court of competent Jurisdiction.

XXII. In *England* and in such Boroughs and Towns as aforesaid in *Ireland* all Persons who may think themselves aggrieved by any Act or Decision of any Inspector or Inspectors of Meters, or by any Order, Judgment, or Determination of any Justice of the Peace, Mayor, or Chief Magistrate, relating to any Matter or Thing in this Act mentioned or contained, may appeal to the Justices of the Peace, Recorder, or other presiding Officer at the then next practicable General or Quarter Sessions to be held for the City, Borough, or County within which the alleged Cause of Appeal shall arise, first giving Seven Days' Notice in Writing of such Intention to appeal, and the Grounds and Nature thereof, to the Party against whom such Complaint is intended to be made, and forthwith after such Notice entering into a Recognizance before some Justice of the Peace, Mayor, or other Chief Magistrate, with Two sufficient Sureties, conditioned to try such Appeal and abide the Order and Award of the said Court thereon; and the said Justices, Recorder, or other presiding Officer shall either hear and determine the said Complaints at such General or Quarter Sessions, or, if they think proper, shall adjourn the Hearing thereof till the following General or Quarter Sessions of the Peace to be held for such City, Borough, or County; and the said Justices, Recorder, or other presiding Officer may, if they or he see cause, reverse or alter such Decision, and mitigate any Penalty or Forfeiture, and may order any Money to be returned which may have been levied in pursuance of such Order or Determination, and may also order any such further Satisfaction to be made to the Party injured as they or he shall judge reasonable, and may also order such Costs to be paid by the Party com-

plained against to the Party appealing, or *vice versa*, as they shall think reasonable.

XXIII. Where any Municipal Corporation, Local Board of Health, or Two or More Justices, or any other Corporation or Person now have Powers of appointing Inspectors of Meters, and they or such Inspectors now have Powers of stamping, re-stamping, examining, or testing Meters, those Powers and the Provisions of this Act shall not be cumulative, but after the Expiration of Nine Months after the passing of this Act the Provisions of this Act shall supersede all such Powers.

XXIV. No Proceeding to be had or taken in pursuance of this Act shall be quashed or vacated for Want of Form, or be removed by Certiorari or by other Writ or Proceeding whatsoever into any of Her Majesty's Courts of Record at *Westminster* or elsewhere, any Law or Statute to the contrary notwithstanding.

XXV. In *England* and in such Boroughs and Towns as aforesaid in *Ireland* all Fees and Penalties received and recovered under this Act shall be applied in aid of the Stock or Fund out of which the Expenses of carrying the Act into effect shall be defrayed, and in *Scotland* all Penalties incurred under the Provisions of this Act shall be recoverable, with Expenses, either before the Sheriff of the County or the Magistrates of the Burgh or Town Corporate wherein the same may be incurred or where the Offender may reside, or before Two or more Justices of the Peace of such County, at the Instance either of the Procurator Fiscal of Court or any Person who may prosecute for the same; and the whole Penalties, after deducting all Charges, and such Remuneration to the Person prosecuting as the said Justices shall think fit, shall be applied in aid of the Funds liable under the Provisions of this Act to the Cost of providing and maintaining Copies of the said Models in the Place where such Penalties shall be awarded; and it is hereby provided that it shall be competent for the said Courts respectively to proceed in a summary Way and to grant Warrant for bringing the Parties complained of before them, and upon Proof on Oath by One or more credible Witnesses, or on the Confession of the Offender, or on other legal Evidence, forthwith to give Judgment on such Complaint without any written Pleadings or Record of Evidence, and to grant Warrant for the Recovery of such Penalties and

Expenses decerned for, failing Payment within Fourteen Days after Conviction, by Poining, or by Imprisonment for a Period, at the Discretion of the Court, not exceeding Sixty Days, it being hereby provided that a Record should be preserved of the Charge and of the Judgment pronounced.

XXVI. In *Scotland* if any Person or Persons shall feel themselves aggrieved by the Sentence of any Sheriff or Magistrates of Burghs or Town Corporate, or Justices of the Peace, pronounced in any Case arising under this Act, it shall be lawful for such Person or Persons to appeal to the Court of Justiciary at the next Circuit Court, or where there is no Circuit Court to the High Court of Justiciary at *Edinburgh*, in the Manner and under the Rules, Limitations, and Conditions contained in an Act passed in the Twentieth Year of the Reign of His Majesty King *George* the Second, entitled *An Act for taking away and abolishing Heritable Jurisdictions in Scotland*, with this Variation only, that such Person or Persons so appealing shall, in place of finding Caution in the Terms prescribed by the said Act, be bound to find Caution to pay the Penalty or Penalties and Expenses awarded against him or them by the Sentence or Sentences appealed from in the event of the Appeal or Appeals being dismissed, together with any additional Expenses which shall be awarded by the Court in dismissing the said Appeal; and it shall not be competent to appeal from or to bring the Judgment of any Sheriff or Justices of the Peace acting under this Act under Review by Advocation, Suspension, or Reduction, or any other way than as herein provided.

XXVII. In all Actions brought against any Person for anything done in pursuance of this Act, or in the Execution of the Powers or Authorities thereof, such Action shall be laid and brought in the County within which the Cause of Action shall have arisen, and the Defendant or Defendants in such action may plead the General Issue, and give this Act and the special Matter in Evidence at any Trial to be had thereupon, and that the Acts were done in pursuance or by Authority of this Act; and if they shall appear to have been so done, or that such Action shall have been brought otherwise than as herein-before directed, then and in every such Case the Jury shall find for the Defendant or Defendants; upon which Verdict, or if the Plaintiff or Plaintiffs shall become nonsuited, or shall

suffer a Discontinuance of his, her, or their Action after the Defendant or Defendants shall have appeared thereto, or if a Verdict shall pass against the Plaintiff or Plaintiffs therein, or if upon Demurrer or otherwise Judgment shall be given against the Plaintiff or Plaintiffs, the Defendant or Defendants shall have his, her, or their Costs, and shall have such Remedy for recovering the same as Defendants have for recovering Costs of Suit by Law in any other Cases.

XXVIII. No Plaintiff shall recover in any Action for any Irregularity, Trespass, or other wrongful Proceeding made or committed in the Execution of this Act if Tender of sufficient Amends shall have been made by or on behalf of the Party or Parties who shall commit such Irregularity, Trespass, or other wrongful Proceeding before such Action brought; and in case no Tender shall have been made it shall be lawful for the Defendant or Defendants in any such Action, by Leave of the Court wherein such Action shall depend, at any Time before Issue joined, to pay into Court such Sum or Sums of money as he, she, or they shall think fit, whereupon Proceedings, Order, and Adjudication shall be had and made in and by such Court as in other Actions where Defendants are allowed to pay Money into Court.

SALES OF GAS AMENDMENT ACT.

756. AN ACT TO AMEND THE ACT FOR REGULATING MEASURES USED IN SALES OF GAS.

[28th August, 1860.]

Whereas, Delays have occurred in preparing the Models of Measures, according to the Provisions of an Act passed in the last Session of Parliament, intituled *An Act regulating Measures used in Sales of Gas*, and it is expedient to defer the Time when several of the Provisions of the said Act come into operation, and further to amend the same: Be it enacted by the Queen's most Excellent Majesty, by and with the Advice and Consent of the Lords Spiritual and Temporal, and Commons, in this present Parliament assembled, and by the Authority of the same, as follows:

1. Except as to Things done before the passing of this Act under the Authority of the said Act, where in the

said Act anything is required to be done within a specified Time after the passing of the same, such Time shall be calculated as if the Thirteenth Day of *October* One thousand eight hundred and sixty had been the Date of the passing of the said Act: Provided always, that, notwithstanding anything in the said Act contained, the said Act shall not come into operation in any County of *England* until the Magistrates of such County in Quarter Sessions, or in any County in *Scotland* until the Commissioners of Supply of such County, or in any County of *Ireland* until the Grand Jury of such County shall have resolved to bring such County under the Operation of the Act.

II. This Act and the recited Act shall be construed together as One Act, and all Penalties and Forfeitures incurred under the Provisions of either Act shall be sued for and recoverable in all Counties, Ridings, or Divisions in *England* and *Ireland* before Two or more Justices of the Peace at Petty Sessions, or before the Mayor or other Chief Magistrate of any City, Borough, Town, or Place.

757. In accordance with the provisions of the third clause of the "Sales of Gas Act" the following standards of cubic capacity were accordingly constructed under the direction of the then Astronomer Royal, namely, a measure of such capacity as to contain 62.321 pounds of distilled water at the temperature of 62° Fahr., and with the barometer at 30 inches (which measure is usually called the cubic foot bottle), and three gasholders of the respective capacity of one and one-tenth, five and five-tenths and eleven cubic feet. In 1871 the Royal Commissioners of Weights and Measures increased the number of gas measures by including gas meters of a very perfect character as secondary standards.

758. The Standards Department of the Board of Trade have issued regulations with regard to certain of the standards mentioned in the above acts, part of which regulations are set forth below, and are followed by makers of the instruments in question:

Gas-Meters.

759. The standard gas-meter to be used in testing ordinary meters (in place of a gasholder) should be a wet meter, and it may be of any capacity up to 100 lights. Although it is desirable that in form and general arrangement it should be a copy of the Board of Trade model, yet no meter will be refused for verification which may differ from the model in external dimensions, in fittings, or in the graduation of the dial. The "wheel" of the meter should be submitted for examination.

The meter should, however, always be fitted with:

1. An adjustable "overflow" both in the back and front of the meter. The position of these "overflows" will be adjusted and sealed at this office.
2. A glass gauge in front of the meter or a side gauge on which the true water-line will be marked at this office.
3. A cross spirit-level on the top of the meter, by which the level of the meter may be ascertained.
4. A dial to show at least one-hundredth of a cubic foot.
5. An outlet tap or valve.

The true water-line will be marked at this Office on the meter when it is passing its normal capacity per hour, under a pressure on its inlet of $\frac{1}{16}$ ths of an inch; and the meter will be tested according to the following rules:

760. Rules for Testing Meters.

1. For soundness, under three inches pressure.
2. For steadiness of light, when burning gas at the rate per hour marked on the meter.
3. For accuracy of measurement—
 - (a) When passing six feet, or one light per hour at a pressure of one inch.
 - (b) When passing the whole quantity per hour marked on the meter under a pressure of five-tenths.
 - (c) When passing the whole quantity per hour marked on the meter under a pressure of two inches.

(d) When passing double the quantity per hour marked on the meter under a pressure of two inches.

4. Examination of index and registering apparatus.

761. It is desirable that the screw-threads of all pipes, connections, or caps and linings on gas-meter standards should agree in diameter, and in the number of threads per inch, with the sizes approved by the Department, as follows:

STANDARD SIZES FOR THE CONNECTING PIPES AND FITTINGS
USED WITH GAS METERS.

Size of Meter	Size of Connecting Pipe or Union of Gas Meter						
	"Boss"			"Cap"			"Lin- ing"
	Mean Diam- eter of External Screw	Number of Threads per Inch	Exter- nal Diam- eter Shank	Mean Diam- eter of Internal Screw	Num- ber of Threads per Inch	Height of Cap	Exter- nal Diam- eter
Lights	Inch		Inch	Inch		Inch	Inch
150	3.70	11	3.10	3.55	11	1.20	3.10
100 }	3.10	11	2.40	3.00	11	1.00	2.40
80 }							
60	2.45	11	2.10	2.35	11	0.80	2.10
50	2.25	11	1.85	2.15	11	0.70	1.85
30	2.05	11	1.60	2.00	11	0.70	1.60
20	1.85	11	1.40	1.80	11	0.60	1.40
10	1.45	11	1.10	1.40	11	0.60	1.10
5	1.15	12	0.85	1.10	12	0.50	0.85
3 }	0.98	18	0.70	0.94	18	0.50	0.70
2 }							
1	0.88	20	0.60	0.84	20	0.40	0.60
0	0.70	20	0.50	0.66	20	0.40	0.50

762. *Gasholders.*

1. *Form.*—Every gasholder should be similar, in gen-

eral form, to the models deposited at this office, and should be made of suitable metal.

2. *Scales*.—The bell may either have two vertical scales or one vertical scale only. If one vertical scale only is provided, a cross-spirit level is to be fixed on the top of the bell, so that the bell may always be used in the same vertical position.

The scales should be graduated throughout into cubic feet, and decimal sub-divisions of a cubic foot.

For the accurate reading of each scale there should be firmly attached to the gasholder tank a pointer or a telescope.

3. *Error*.—No variation from true standard of more than one-quarter per centum either in excess or in deficiency will be allowed on any standard gasholder.

4. *Pressure-gauge*.—A pressure-gauge is to be fixed either on the top of the bell or on the outlet pipe of the gasholder.

5. *Thermometer*.—An accurate Fahrenheit thermometer is to be also fixed either on the top of the bell or on the outlet pipe of the gasholder.

6. *Balance*.—The bell must be exactly balanced, either by a cycloidal counterpoise or by other approved means, at all depths of immersion.

763. METHODS OF GRADUATING THE STANDARD GAS MEASURES.—The merit of having been the first to contrive a means for transferring a cubic foot of air directly from the cubic bottle into the gasholder to be measured belongs to Mr. George Glover, although Mr. Hartley, independently, and without any knowledge of what Mr. Glover was doing or had done, also devised a method for effecting such transference of a cubic foot of air. Mr. Glover's arrangement is shown in Fig. 87. The bottle is suspended upside down from a frame of iron firmly fixed by screws to the upper part of a box, within which is a water-tank of somewhat greater depth than the bottle. The tank is suspended by two cords, which pass through pulleys at the top of the iron frame to the barrel of a winch fixed on the lid of the box, the lid being secured in the position shown in the cut by bolts or screws

The plug of the cock of the bottle is removed before it is mounted, and the end of the cock-barrel covered by two discs of plate-glass, firmly held in position between brass plates bolted together. Finally a bent pipe fitted with a

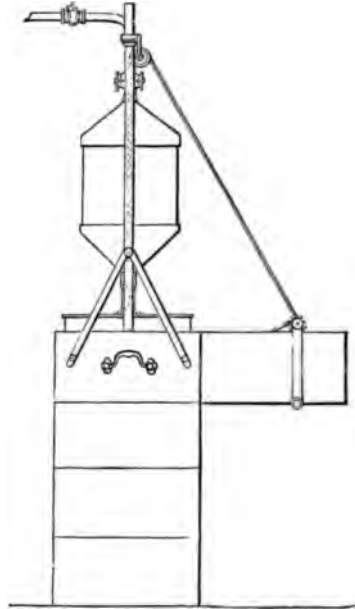


FIG. 87.—GEORGE GLOVER'S CUBIC FOOT BOTTLE.

stop-cock is attached permanently to the neck of the bottle, as shown in the woodcut. From this pipe a tube connection is made to the holder to be tested. The tank, being charged with water, is raised by turning the handle of the winch until the whole of the air is expelled from the bottle and water appears in the barrel of the cock between the glass plates; the cock on the bend is then closed, as is also the gas-holder cock. An intermediate ventcock on the connecting pipe and the cock of the pipe on the bottle are opened, then the tank is lowered to its original position. The operations

are repeated as many times as necessary. To render the instrument portable, the frame and winch are taken off the box which receives the bottle and fittings.

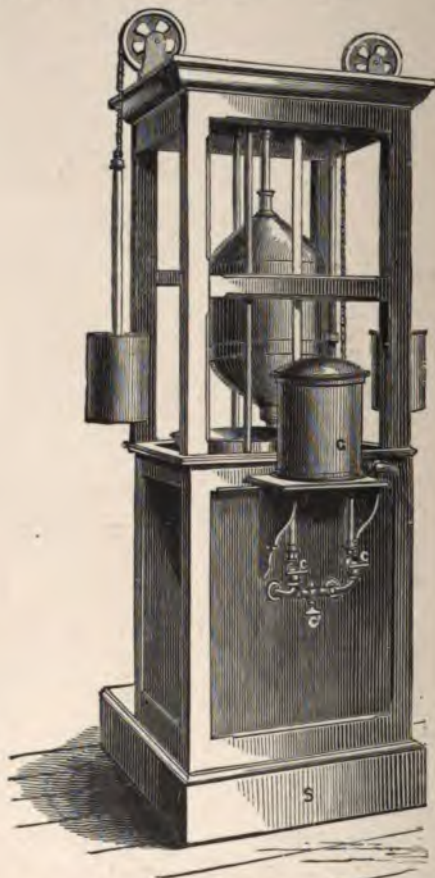


FIG. 88.—HARTLEY'S CUBIC FOOT TRANSFERRER.

764. Mr. Hartley's arrangement for using the bottle as a direct transfer is shown in Figs. 88 and 89, which represent a standard instrument similar to those made for the Canadian, South Australian and Dutch Governments.

765. Mr. Hartley's method demands but little labour to operate, for in addition to the counterpoises four loose weights are provided, and by placing these in pairs on *W*,

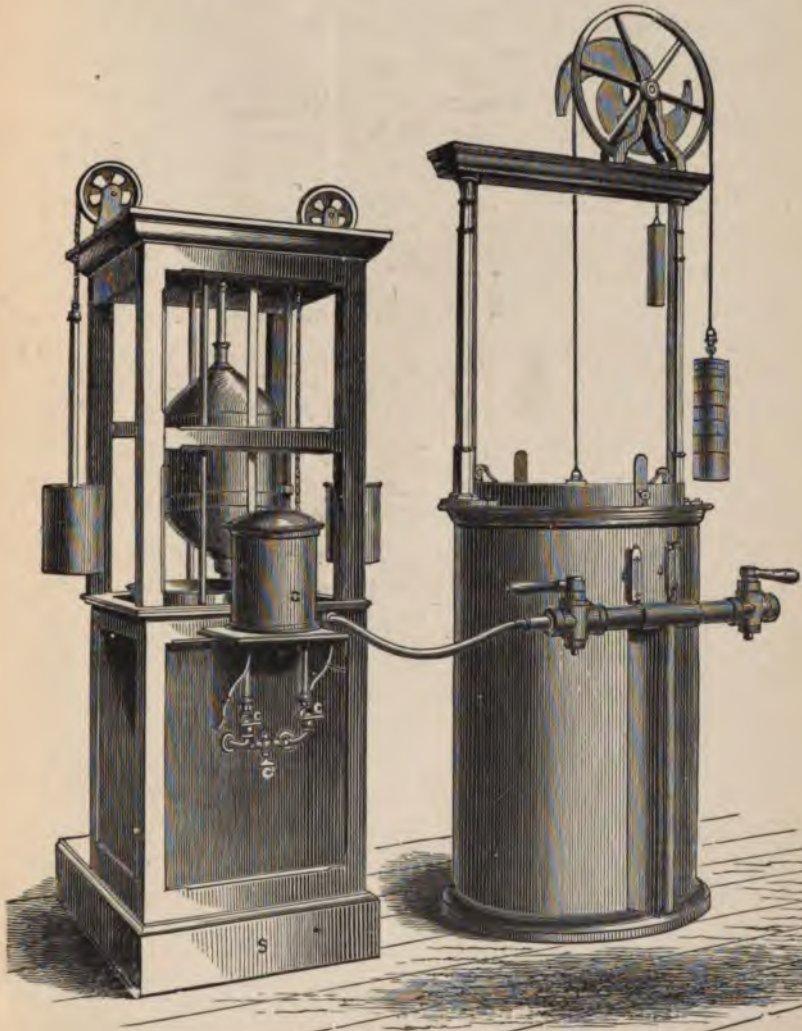
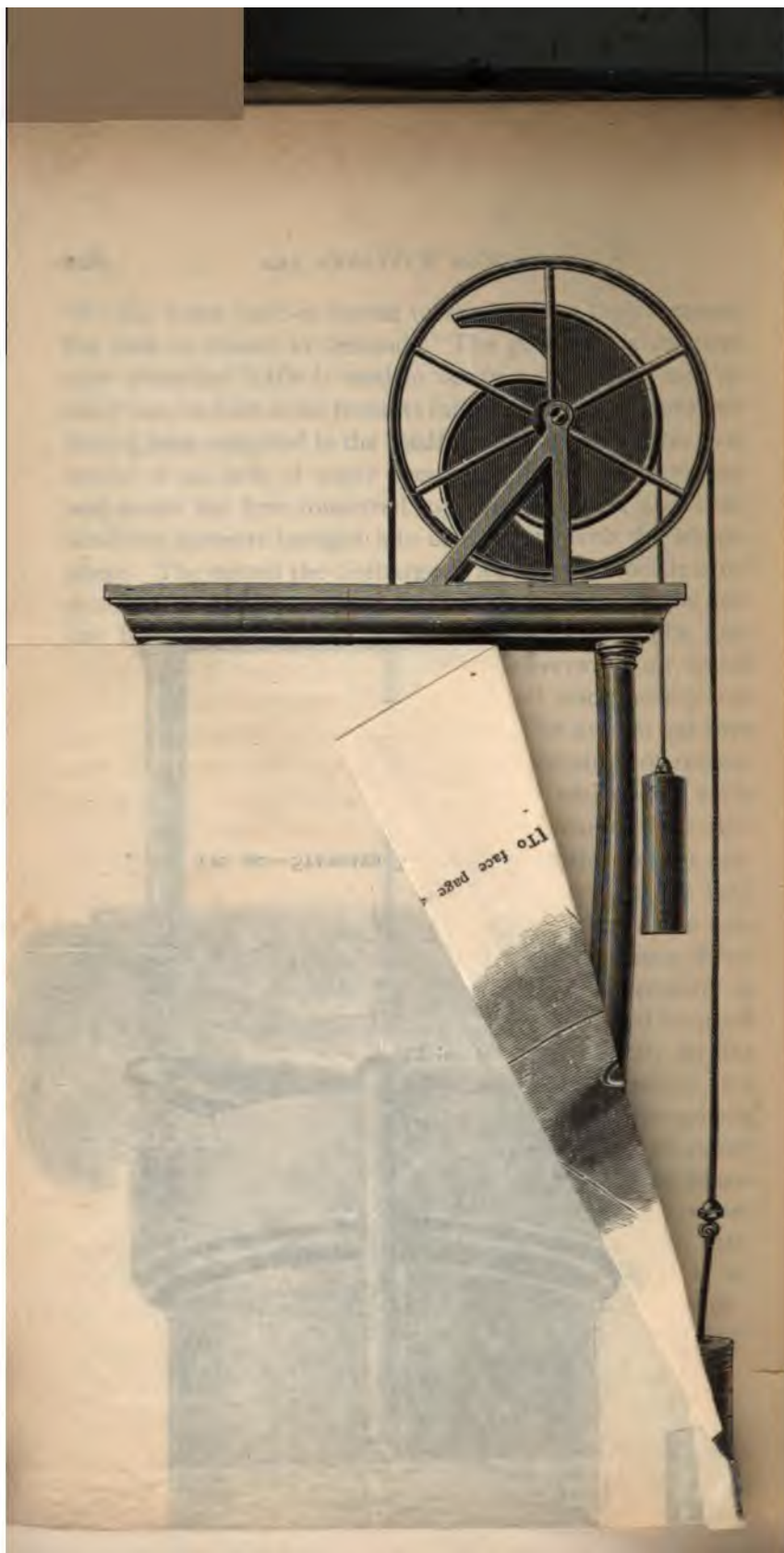


FIG. 89.—HARTLEY'S TRANSFERRER IN USE.

W', the water tank is caused to rise, and by their removal the tank is caused to descend. The governor is required only when the bottle is used to verify a gas meter, and no error can, or does, arise from its intervention. The governor having been weighted to the needful extent (say, to give five-tenths of an inch of water pressure), the bottle, governor and meter are first connected together by pipes, and their aëriform contents brought into equilibrium with the atmosphere. The instant the discharge of air from the bottle commences, the governor comes into action, and when the air has been completely discharged from the bottle the gas-holder of the governor descends and delivers the air which it has received through the meter, and all once more comes into equilibrium with the atmosphere. The system has been severely tested, and appears both on the grounds of reasoning and of demonstration to be free from objections, while it certainly possesses strong claims on account of its simplicity, the small amount of trouble it demands, and the continued use of the same volume of water, which last may therefore be readily brought to and maintained at a due temperature. It is to be understood, however, that such direct measurement from the bottle is by no means a necessity in the case of a meter, and can only be readily applied to small meters. The method of measuring meters directly by the transferrer, moreover, does not give absolute accuracy, for the cubic foot of the bottle is a cubic foot under atmospheric pressure only; but the error is very small, inasmuch as under a mean barometric pressure, and with a meter or other measure opposing a resistance of so much as half an inch water pressure, the reduction in volume would be no more than $\frac{1}{768}$ th part, or just over $\frac{1}{8}$ th per cent. The error is so small that it has been disregarded by the Referees in devising their $\frac{1}{16}$ th cubic foot direct transferrer for testing the Photometer meter.



766. There is another form of cubic-foot measure in use, that devised by the Metropolitan Gas Referees and prescribed by them for use in the London Testing Stations up to 1898, when this method was abandoned for the $\frac{1}{12}$ th cubic-foot measure. The Referees' cubic-foot measure does not bear strictly upon this section, which deals with testing under the "Sales of Gas Act." Particulars of the method will be found in Appendix J.

767. STANDARD TEST GASHOLDERS.—The Government Standard Gasholders are very elaborately finished and beautiful instruments, far too costly for general use. In principle of construction they are identical with those employed by Public Inspectors and others for the verification of gas meters in this country, in the colonies and abroad. By these standards the working or "Inspection Standards," as they are called, are verified, and the divergence, or error, in the latter must not now exceed a quarter of a per cent., only one-half the error formerly allowed, but which is nevertheless amply sufficient. The description which follows applies specially to "Inspection Standards," and generally to the Government Standards.

768. An instrument of this kind, Fig. 90, consists, like an ordinary gasholder, of a water-tank and a cylindrical bell or holder fitting into the tank. The holder is free to rise to a certain height, and is made to contain a specific volume of air or gas, and it is constructed in such a manner as to fulfil the following conditions, viz.:

- (1.) The vertical descent of the holder while its contents are being discharged.
- (2.) The adjustability of its operating weight, so that it shall deliver gas at any pressure up to a pressure equal to 3 inches head of water.
- (3.) The uniformity of its pressure, whatever it may be, throughout the descent of the holder.
- (4.) Great accuracy in its measurement.

769. The general construction and action of a test gas-holder will be understood from the following remarks and explanations:

770. The vertical descent of the holder is secured by affixing to the top and bottom of the holder a certain number of guide-wheels. Those at the top of the holder run against pillars, which rise from the edge of the tank, while the bottom wheels run against guide-plates within the tank.

771. Secondly, the holder is made heavier than is requisite for it to give the maximum pressure, and is suspended from the end of a cord or strap, which passes over the grooved wheel on the beam above the pillars, and sustains also a series of counterpoise weights, the removal of one or more of which causes the holder to discharge its contents at pressures ranging from one-tenth of an inch up to 3 inches head of water.

772. Standard Gas Holders are also provided with a heavy pressure weight, by means of which a pressure of 6 inches can be thrown. This pressure weight is made in two ways, either to operate when placed upon the top of the bell or by being removed from the balance weights. In either case the weight is raised or lowered by means of a drum fitted with ratchet and pawl.

773. In respect to the third condition: When the holder is immersed it necessarily displaces a quantity of water equal to the bulk of the metal composing the holder's circumference. If we assume the specific gravity of this metal to be seven times that of water and its bulk to be one-tenth of a cubic foot, then the weight of the metal immersed would be 43.62 pounds, one-seventh of which, or 6.23 pounds, would be the weight of the water displaced, and also be the weight which the holder would lose by immersion. To compensate for this loss and to render the pressure of the holder equal throughout its descent, a spiral curve and a weight are em-

ployed. The spiral is formed upon and curves inwards nearly to the centre of a metal plate, which is fixed on to the end of the spindle upon which the large grooved wheel revolves. The weight, which is proportioned to the compensation required, is suspended by a cord from the outer end of the spiral. When the holder is raised to its greatest elevation the weight acts with its greatest force. As the holder descends the large wheel partly rotates, and the spiral is also turned, so that the cord approaches the centre; the leverage thereby becomes less, and the effective "pull" of the compensating weight diminishes in exact proportion to the weight lost by the holder throughout its descent into the water. Formerly the compensating curve was made with *one* arm only, and its varying leverage, as it changed its position by rotation, caused irregularities in the pressure given by the holder. To obviate this evil Mr. Hartley years ago constructed the compensated, or two-arm, curve shown in the wood-cut.

774. Another method of compensating for the loss of weight caused by the immersion of the bell in water is that known as the chain method. In this system of compensation the chain requires to be of such weight that a length equal to the stroke of the bell shall be half the weight which the bell loses by immersion, for obvious reasons. Another method is to syphon off water from a chamber attached to the bell as the latter rises, and the capacity of this chamber is such that the automatic ingress or egress of water from it compensates. Either of the above systems, properly carried out, are accepted by the Standards Department.

775. Accuracy in measurement is secured by filling the bell of the gasholder with air by successive discharges from an exact duplicate of the Government cubic-foot bottle, marking the elevation of the bell, for each cubic foot of air thus delivered into it, on two vertical scales, one affixed to

the front and the other to the back of the bell. The primary divisions thus determined are sub-divided so as to indicate tenths and hundredths of a cubic foot. When the gasholder is properly levelled and adjusted the relative divisions on the two scales will agree, but if the holder be not levelled and adjusted properly the divisions will not coincide. In practice the front scale alone is generally regarded. In order to enable the scales to be accurately observed a pointer or some other appliance is fixed upon the tank opposite each scale.

776. Gas or air is admitted to and discharged from the holder through a stand-pipe, which is fitted to the front of the tank, and also passes up the centre of the tank to a few inches above the water line. The front or external part of this pipe is fitted with two cocks, and with a pressure-gauge and a thermometer to show the pressure and temperature of the issuing gas. It is also provided at the lower part with a socket and plug, so that any water which may by accident have entered the pipe may be drawn off. The tank is further provided with a cock at the water line, and with a plug or cock at the base for discharging the water when needful.

777. It will be seen by reference to the Standards Department Regulations (pars. 759 to 762) that, though specifying the principles which a Standard Test Gas Holder must embody, nothing whatever is said as to points of detail. Consequently, there are various differences in these between holders constructed by different makers. The following are some points which should be observed in selecting a holder

(1) The tank should be of cast-iron, and be fitted with a water-line cock and a run-off cock with a connection left screwed for barrel.

(2) The cocks should be of gun metal, of full way, made so as to turn easily and at the same time be perfectly sound. They should be fitted with stops, and a

spanner should be provided for each cock and be fixed to same.

(3) The gasway box to which these are attached should be a casting and fitted with a thermometer, a 6" or 8" pressure gauge and a vent cock.

(4) The connection between the inside stand-pipe and the outside one should slope towards the latter, and should be provided at the bend or elbow, with a plug to drain off any water.

(5) The bell should be of stout material stayed at the top and bottom, and having a dome-shaped top, so that there are no crevices in which dust, etc., can accumulate.

(6) The guide wheels should be of gun metal, and the top ones should be mounted on adjustable brackets. The periphery of the guide wheels should be concave, working against circular guides.

(7) The scales should be of brass, and be legible and distinct. They should preferably be fastened to the bell by means of blocks and screws, because they can, if removed for repairs, be put back in their correct place, this not being easy where the scales are held by metal clips.

(8) The top wheel of holder should work in anti-friction bearings, and not in an ordinary journal or one with a single wheel. These anti-friction wheels should be of gun metal, the spindle of wheel being, of course, of steel.

The compensator should be a cycloid or other approved method, with means (if the cycloid is used) of adjusting its position with reference to the bell, and this position should be indicated.

778. To fit up a holder proceed as follows:

(a) Place the tank in the position which it is to occupy on a solid, firm, and level base.

(b) Place the graduated bell within the tank, with the side which is so marked to the front of the tank.

(c) Place the two pillars in their respective positions (indicated by corresponding numbers or marks) on the top of the tank, and secure them loosely, but safely, to the tank by means of the bolts furnished. In setting the pillars up take care that the top wheels of the bell run easily in the guides.

(d) Place the beam on the tops of the pillars and secure it, but not too tightly, to the pillars by means of the screws provided. No mistake can be made, as the screw holes and the tops of the pillars are marked.

(e) Fix the front and back brackets on to the top beam, and see that the anti-friction rollers run freely. Some holders are made with these brackets on the right hand, and some on the left, so that two can be used at one bench. This is generally specified, but unless otherwise stated, holders are made to work on the right hand.

(f) Attach the wire cord by means of its nut to the bell, pass the cord over the wheel, and suspend the back weight only by means of its hook to the eye on the free end of the cord.

(g) Place the compensating curve or cycloid on the square end of the wheel spindle, and secure with the nut. Attach the compensating weight to the nut at the end of the cord, and pass the latter into the groove, so that the weight hangs freely from the curve. With the bell resting on the bottom of the tank, turn the wheel, and with it the cycloid, until the cord cuts, or crosses, the centres of the two holes which are stamped in the plate of the compensating curve, indicating its true position.

(h) Place the loose weights, viz.:

Five, <i>five-tenths</i>	of an inch pressure weights
Two, <i>two-tenths</i>	" " "
One, <i>one-tenth</i>	" " "

upon the back weight.

(i) Next, carefully observe whether the cord by which the weights are suspended hangs parallel with the pillars when regarded both from the side and front of the gas-holder. If it does not, the gasholder must be readjusted until the cord does hang in the manner indicated, or, at all events, very nearly so.

(j) Now charge the tank with water up to the height indicated by the water-line cock, which is a few inches below the top of the tank.

(k) At this stage it is advisable to try the working of the instrument. To do this, place a two-pound weight on the weights (if it be a 5, 10, or 20 cubic foot gasholder), when, the cocks being open, the bell should rise easily to its full elevation. Supposing this to be the case, remove the two-pound weight and place it on the top of the bell as near to the centre as possible, and the bell should

descend with freedom. If there should be any excess of friction the bell may cease to move, or move very sluggishly. In such case adjust the pillars, the wheel standards, etc. (all of which can be sufficiently shifted to ensure freedom in the motion of the bell), and oil the several bearings. Finally, fix the screws and bolts of the various parts. If excessive friction be still manifested, examine the bottom rollers of the bell and the guides in the tank in order to see if they have been injured. There ought to be no difficulty in adjusting the instruments to work easily under an operating weight of two pounds.

(1) Pass the cords from the drum of the pressure weight, which it fitted with handle, ratchet, and pawl, over the wheels on the sides of the beam and hook the large pressure weight to these cords. See that this weight passes up and down freely without fouling the cord by which the bell is suspended.

779. The holder is tested for soundness by closing the cocks and putting on 3" to 6" pressure. After the gasholder has been put into use it should be examined at least weekly,

1. In respect to height of water in tank.
2. Soundness.
3. Position of compensating cord in relation to gauge holes in the plate of the compensating curve.

780. The bell should be drawn to its full height every night after use, and the scales wiped. This prevents discoloration of the painted body of bell and of the scales. Care should be taken that the cocks are turned off.

Standard Test Gas Meters.

781. The Standard Test Meters usually employed for testing meters *in situ* are, respectively, 20-light and 100-light size, and of the wet kind; they were made under the direction of Mr. Hartley (to whose advocacy their adoption was in a large measure due), in accordance with a design submitted by him to the Royal Commission. The meters were.

however, found to be not sufficiently portable, and Mr. Hartley made new models, known as Airey's pattern, which were described and illustrated in the following memorandum issued by the Standards Department of the Board of Trade in 1884.

782. The memorandum is as follows:

"Experience has shown that the Standard 'gasholder' which is used by the inspector of gas meters in testing ordinary meters brought to his office cannot be accurately and conveniently used in testing *in situ* those large meters which may not be removed from the places where they

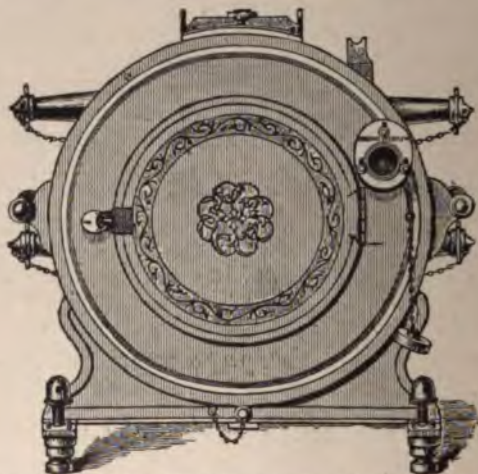


FIG. 91.—STANDARD TEST METER (DISMOUNTED).

are used. In 1871 the Standards Department, at the recommendation of the Standards Commission, caused to be made and legalised certain standard test meters, which have since served as models under the Act. It has been represented, however, by some of the principal inspectors that these models are not sufficiently portable, and other models of a better form have, therefore, now been made and duly verified.

783. "The form of the new 20-light model test-meter is shown as above. Fig. 91 shows the meter dismounted

ready for travelling, the outlet-pipe and all projecting parts liable to injury in transit having been removed and placed in a small tin case which accompanies the meter. Fig. 92 shows the meter mounted ready for use, with the water gauges, levels, and outlet-pipe attached. The weight of this meter dismounted is 70 pounds. It will, of course, pass through any ordinary doorway; and its cost, with fittings complete, should not exceed £35. It is adapted for testing any meter from 20 lights to 100 lights,

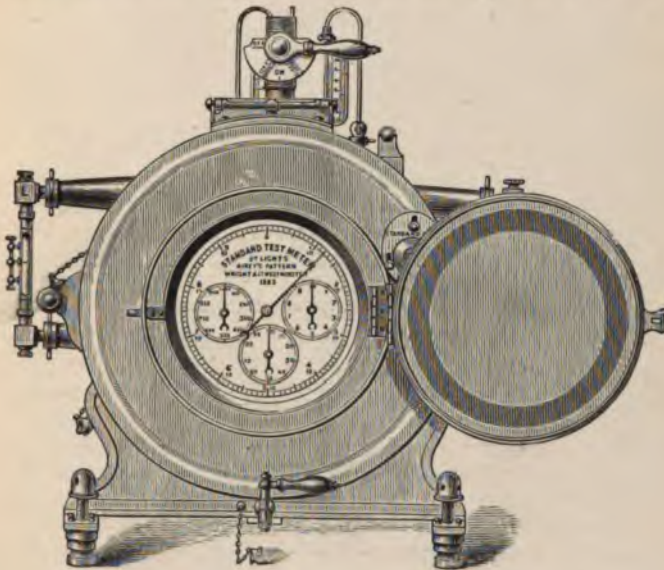


FIG. 92.—STANDARD TEST METER (MOUNTED).

a large standard of nominally 100 lights being necessary for testing larger meters.

784. "The Standard meter has levelling screws, and is provided with the following external fittings: Two water-level gauges, one on each side; two spirit-levels resting in cradles on the top of the meter; two pressure gauges, one in communication with inlet and the other with outlet; two thermometers, one on the meter to indicate temperature at outlet, the other on the top of the inlet connection; a regulating-cock, with lever placed centrally on

the top; a draw-off water cock at the base in front. All these external fittings can be easily detached from the meter when it is being carried, and fitted in the small tin case above referred to. The points to which the gauges, etc., are attached are furnished with screwed caps, secured against loss by short suspension chains, and, on the removal of the fittings, these caps may be quickly screwed over the points.

785. " In addition to the water-line gauges, the meter is provided at opposite sides, back and front, with adjusting overflow sockets, so shaped as to prevent any 'piling' of the water above the 'weir' over which water is to flow. These sockets are carried on plates slotted vertically; each plate being secured by three screws to the back and front of the meter. With the meter truly level and charged with water, the positions of the overflow sockets are determined when the meter is first verified, and when the screws are tightened; the correct positions being such that the water will cease to flow or drip out when the above level agrees with that indicated by the water-line gauges. Thereafter when the meter is to be used it will only be necessary, in order to ensure the correct water-line, to set the meter truly level, by the aid of its feet screws and spirit levels. In the event of the glass gauges being broken in transit, the meter can also then always be filled to its true water-line.
786. " The pointer of each index on the dial is fixed by a screw, by loosening which the pointer can be shifted and the index promptly set to zero. The gauges, etc., are all marked R or L (right or left), so that no delay in fixing may arise. If the test-meter is worked much above its normal speed of 120 revolutions per hour a small error in registration will ensue, for which the inspector can allow.
787. " The method of using a test-meter is so well known to inspectors that it is not deemed necessary to give details, more especially as published information exists; but it may be pointed out that it is desirable that the gas should first pass through the meter to be tested and then through the standard, and that the standard should be placed as near to the meter as possible, so as to assure uniformity of temperature: the primary conditions for use being also (a) that the meter shall be adjusted to its standard level; (b) that it shall be charged to the exact water-line with water; (c) that it shall as far as practicable be

worked at its normal speed, viz., 120 revolutions per hour, corresponding for—

	Per hour.	Per minute.
A 20-light test-meter	to 120 cu. ft., or	2 cu. ft.
A 100 " "	" 600 " "	or 10 " "

788. "It is necessary that every local authority under this Act should provide their inspectors with duly verified copies of these models. No meters can be legally tested outside the inspector's offices, or fees received for such testings, unless the testings have been made with standards verified by this Department.

"Board of Trade, Standards Department, 1884."

789. A reference to paragraph 759 will show the rules and regulations laid down by the Standards Department with respect to test-meters in 1891, and these are still in force. It is necessary that test-meters, like Standard gasholders, be verified once in every ten years. It should here be stated that the cock which surmounts the meter is furnished with a pointer on its lever, which works over a quadrant and enables the cock to be readily opened to the desired extent. Test-meters should generally in their construction and details agree with those just described, but need not by any means be so elaborately finished and expensive; the extreme dimensions are about as follows:

	20 Light.	100 Light.
Diameter	2'.2"	3'.8"
Depth	1'.6"	2'.6"
Height	2'.2"	3'.8"

It should be stated that in some cases a gasholder arranged in a portable frame is used for testing *in situ*. Such a gasholder is attached to the L. C. C. Westminster Testing Station.

790 It is well understood that when a wet meter is worked above the speed at which its measuring capacity has been determined it becomes "slow" to a certain limited degree, and that the reverse of this takes place when a meter is

worked below its speed and it becomes slightly "fast." The reasons for such variations are as follows:

A meter requires power to drive it; this power must be derived from the gas to be measured, so that the gas must be delivered into and pass through the measuring chambers under some sensible pressure, *i. e.*, in a state of compression greater than that of the atmosphere, and can only be measured while in this greater state of compression. The practical effect of this compression is very small, but sensible and important differences in measurement arise from the displacement of water from the measuring chambers, which displacement increases as the working speed is increased, owing to the greater resistance of the wheel, and renders the meter *slow*; that is, causes it to register *less* than the true volume passed through it.

As the capacity of a standard test-meter is determined at its normal rate of working, and the water-line marked while the meter is working at this speed, and with the pressure of the inlet gas showing $\frac{1}{10}$ " on the gauge, the meter can be made to measure correctly at any speed by the simple process of adjusting the water-line while the meter is working at the rate desired. More water will be required when the meter is worked at a high speed, in order to provide for the difference in the levels within and without the wheel.

791. If the capacity of the meter has been determined at its normal rate of working, and the water-level defined by marking the gauges when the meter is not working, and when only the atmospheric pressure is acting within it, then the meter must always be charged with water to the indicated level when open to the atmosphere; and it must always be used at its normal rate of working, or, if worked at other rates, the percentage of errors due to such rates must be experimentally determined and allowed for. Practically, the error due to varying rates is not likely to exceed about one per cent.

Description of a Testing Station.

792. In a testing station one of the first essentials is provision for dealing with a large number of meters rapidly, but at the same time carefully, and in order to ensure this it is necessary that there should be plenty of space, that the apparatus should be fitted in a convenient manner, and that the station be free from instruments that are liable to get out of order or demand a great deal of attention; and, lastly, that a good system should be observed in dealing with the business of the station. Mr. A. Spencer, the chief of the Public Control Department of the County Council, has kindly placed at the writer's disposal full particulars as to how the business is transacted at the various stations under his control, and the writer feels that thanks are due to him for placing this information before those interested in the subject. To Mr. E. W. Scott, the Chief Inspector of the Westminster Station of the London County Council, thanks are due for many useful details which his experience has found to be necessary in the efficient handling of large numbers of meters, and which have enabled the writer to deal with the subject of Testing Stations from the point of view of an official tester, instead of relying upon his own practical experience as a maker of apparatus and meters.

793. A reference to the drawing, Fig. 93, will make clear the following points:

A Station should be built upon a firm foundation, dry, and free from vibration.

The walls should be thick and without windows, the light being derived from top lights provided with blinds.

All the rooms should be on one level, and so arranged that there is never, except for cleaning or ventilating purposes, any direct way from the outside air to the testing-room.

This is necessary on account of the importance of the

maintenance of a regular temperature, which is equally important whether wet or dry meters are to be tested. The system of heating which is recommended is that of hot water pipes (low pressure) communicating with a boiler heated by a gas furnace, and arranged so that the

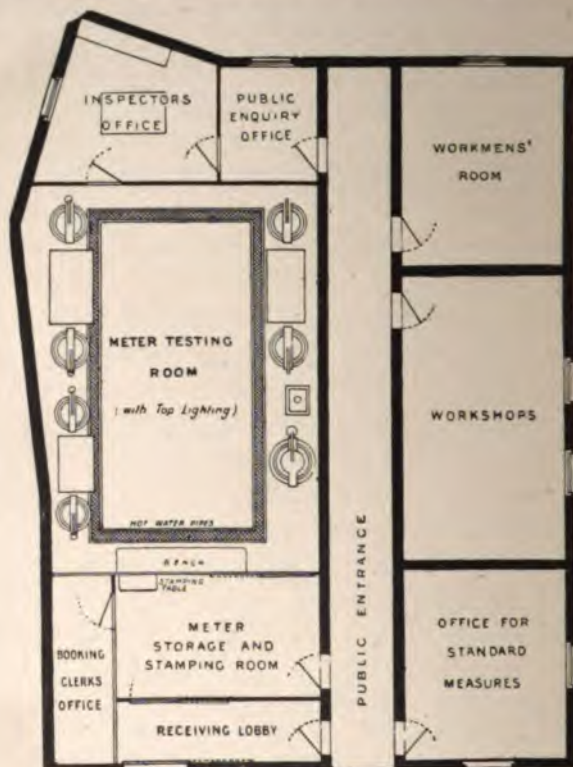


FIG. 93.—PLAN OF METER-TESTING ROOM.

gas supply to the furnace is automatically regulated according to the temperature of the room. This can easily be done by the interception of the boiler gas supply (which should run through the room to be regulated) by a Thermostat, as illustrated in Fig. 26.

794. In order to deal with the meters conveniently there

should be provided a storage room communicating with a fair-sized lobby, and thence with the yard. The storage room should also have its temperature regulated so that dry meters can be dealt with immediately they are brought into the testing-room. Built into both the lobby and the storage room there should be a glazed office for the booking clerk. The receiving and despatching side of the station should be a yard with a lean-to and if the floor of the rooms is 3' 6" from the ground level it will be found that carts can back up with the tailboard level, facilitating the moving of large or small meters. The lobby is provided in order that when the outer doors are opened a van load of meters can be quickly received and booked, and when the outer doors are closed can be passed into the storage room. If this is not so arranged the influx of cold air will materially affect the temperature of this room and the testing-room, causing a stoppage in the testing operations, or otherwise, serious errors to arise. Too much importance cannot be given to the question of temperature, and the adoption of the means suggested would appear to be the simplest way of dealing with the matter.

795. If the plan is consulted it will be seen that the inspector's office commands a view of the receiving-room and the testing-room, so that operations are always under his observation. The testing-room should be well ventilated, with powerful down-draught-preventing, extraction cowls, into the flues of which the pipes conveying the blow-off gas can be carried as to gas service; it will be found advisable to have a main of, say, 3 or 4 inches, connected from an adequate meter and serving the holders only. This meter should be in the testing-room itself. The gas for lighting and other purposes should come off a separate service, being used for the torch-jets, and also serving for a pilot supply to the burners used for the float of lights in testing for

steadiness of flame and for capacity. The utilisation of two services enables a separate account of the gas used for actual testing to be kept. In large stations it may be possible to have a special high pressure gas service connected to the inlets of the holders, so as to facilitate their being filled without the addition of any weight to the counterpoise. In stations where air is used for testing a service of air under pressure (or capable of being put under pressure by a foot-bellows or other pump) is sometimes used. The general practice is, however, to use gas at main pressure and to draw in the air (when required) by the exhaust of the holder itself through an air cock fitted into the stand-pipe of the gasholder.

796. As to water supply: It is recommended that the water used in testing wet meters should be drawn from tanks forming the proving benches, as by that means the water is, as is very necessary, of approximately the same temperature as the gas. This equality of temperature can be obtained in many other ways, but Mr. Hartley's system is probably as convenient as any other. The water supply should be run so that the gasholders and large wet meters can be filled easily, and there should be proper facility for emptying the gasholder tanks and disposing of waste water.

797. The following is the apparatus which should be provided in each testing station. The drawing (Fig. 94) shows a bench fitted up with two gasholders and apparatus, which can, of course, be duplicated to any extent, and with 5-foot instead of 10-foot holders. Where 20-foot holders are provided they should always be used for testing large meters. No bench is required, but a suitable space and connections for large meters should be provided.

Standard Test Gasholders.—Several 5-, 10-, and 20-foot gasholders will be required, according to the number of

meters to be tested. As a rule, two or three holders are sufficient, but in large towns four or six gasholders are needed. They are all of the same type, of which a description is given in paragraphs 768 to 777. Five-foot holders are used for testing small meters and for soundness, 10-foot holders for testing larger meters, while 20-foot holders are not general, although they should be, as by their use meters whose testing-dial shows more than 10 feet per revolution can be tested without the necessity of coupling two smaller holders. The

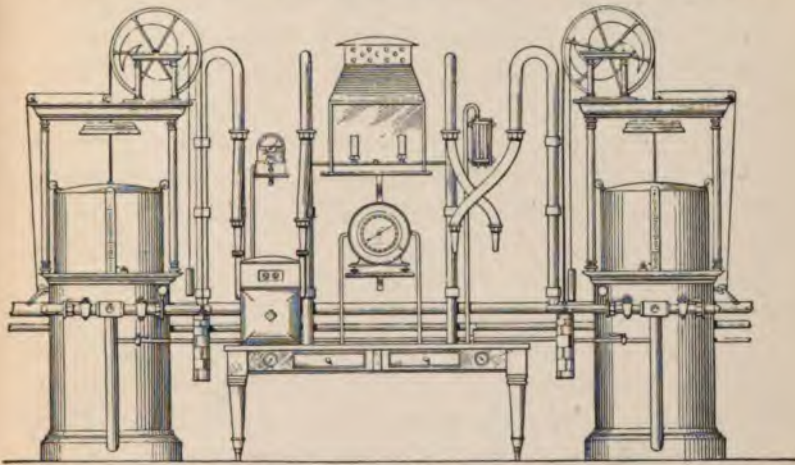


FIG. 94.—ELEVATION OF METER-TESTING BENCH.

20-foot holder, being deeper than the smaller sizes, is generally fixed below the floor level, so as to bring the pointer to a convenient height for reading. The approximate depth and diameter of 5-, 10-, and 20-foot holder tanks are as under:

	5	10	20 feet.
Depth	3'.7"	3'.7"	4'.3"
Diameter	2'.4"	2'.11"	3'.6"

Proving Bench.—This may be a strong table of wood with a lead covered or a slate top, which must be perfectly

level, or it may be a cistern about 5 feet 6 inches to 6 feet long, 2 feet 6 inches wide, and 2 feet 6 inches deep; its elevation to the needful height being effected by placing it upon blocks or brickwork, leaving a part of the space below open from back to front. The edge of the front plate of the cistern should be 1 inch above, and the edge of the back and end plates 3 inches above the level of the top slab. The top slab should be 1 inch or $1\frac{1}{4}$ inches thick, the edges, in the direction of its length, should be rebated, and the upper surface be planed perfectly flat. The width of the top should be 3 inches less than the internal width of the cistern, and it should be so adjusted as to leave an opening along the back of the cistern 2 inches wide, and an opening the front of the cistern 1 inch in width. These openings should be covered with strips of perforated zinc, fitting upon the rebates of the top and into saw-cuts in the back and front plates. The gratings, thus formed, permit the free flow of water into the cistern when wet meters are being emptied, after having been tested. The raised edges round the top of the cistern prevent the slopping over of water. The cistern should be fitted with water-supply pipe and ball-cock, and with an overflow or waste-pipe. As the water has to be drawn from the cistern for the purpose of charging wet meters, a small pump also is required, which may be fixed on the cistern or be placed in any other situation which may be more convenient. It is not necessary that all benches should be constructed in the manner described above, but only one or two for use in testing wet meters. A strong bench, as shown in Fig. 94, is all that is required for testing dry meters.

Mirrors.—The back of the bench (either form) should be fitted with mirrors, inclined at a proper angle so as to enable the operator to see instantly any small leaks at the back of the meter or water leaks and “liquor” leaks which might otherwise escape detection. The writer believes that

Mr. E. W. Scott was the first to introduce this useful innovation at the L. C. C. Westminster office, of which he has charge.

Float of Lights.—It was formerly the custom to burn off most of the gas passing through the meters under test at a rail or float of burners. This practice is now discontinued and the gas is burnt at an Argand burner in a suitable glazed case (see illustration), the remainder of the gas being blown off. This is facilitated by the

Connecting pipes, which, in addition to being fitted with the necessary swan-necks, rubber tubes, and interchangeable connections for different size meters, are also fitted with a quadrant cock, regulating the passage of the gas after the meter. This quadrant can be empirically graduated and marked at the different positions of the cock lever, which will allow the gas at given pressures to pass at the various rates required in testing for correctness of registration. Between the outlet of the gasholder and the inlet of the meter to be tested a small pipe is led, forming a connection to

A King's gauge or water gauge with a 9- or 10-inch range, by means of which the pressure at which the test is made can be clearly seen, and the test for soundness of case also made with absolute stringency, as explained in paragraph 827. This heavy-pressure-test is the more necessary where prepayment meters are being tested, for the reasons explained in that paragraph. Where a King's gauge is used it should have an open scale, while a water gauge should either have coloured lines on the back of the glass and be mounted on a white background, or have the water tinted with a little colouring matter such as fluorescene.

A clock is also required, firstly, as a timepiece; secondly, as a means of timing the rate of gas consumption in testing either for soundness or for registration. For this purpose the clock should indicate legibly seconds, minutes, and

hours, striking at each minute and going for eight days. A dead-beat pendulum wall clock is the best for the purpose, because easily regulated. The ascertaining of "rate per hour" is facilitated by the provision, as an addition to each gasholder, of a central-dial meter, but this is not an absolute necessity.

Sundries.—Each bench should be provided with two gas-torches, arranged with a suitable hook for suspension when not in use, a cock for regulating the length of the jet, and a flexible tube to enable the torch to be passed to the argand burner. A good thermometer in case should also be provided for each gasholder (in addition to the one fixed in the stand-pipe) for taking temperatures of water or air, as may be required. A small tray might also be provided for each operator, in which he can keep chalk and the unfortunately indispensable putty. When all meter unions are universal it will be possible to connect the meter under test by fly-caps, but at the present time it is sometimes impossible to dispense with putty to make sound the inlet and outlet connections.

Each man should be provided with a slate, a few tools, such as screwdriver, pliers, ice-picker, etc., and also a set of mounted percentage of error tables similar to those which will be found in appendix.

798. Apart from the above, which (with the exception of the clock) should form part of the outfit for every pair of holders, the following can with advantage be fitted in a meter-testing station:

Test Meter.—Apart from the Standard Test Meters which will be provided for outside testing purposes, it is well to have fixed on a separate bench a 20-light test-meter of modified form, so that in case of a dispute, or any doubt as to the accuracy of an index, the consumer's meter in question can be tested in connection with the test-meter and a long and exhaustive comparison made. The provision of

such a meter will often be found to save much time and trouble.

Stamping Table.—A small bench fitted with proper Bunsen burner for sealing the meters which have to be stamped will be found useful. Such a bench would be fitted with receptacles for the wax, and with a drawer for the seals, etc.

Trolleys.—It will be found useful to have one or two trolleys of the "Samson" model for facilitating the moving of meters.

Workshop.—It will also be advisable to have a well-fitted workshop in connection with each testing station for the carrying out temporarily of repairs, alterations, and odd jobs which from time to time are necessary.

Generally.—It should be borne in mind that a little care in keeping the station and instruments clean and in good order is very necessary, if large quantities of meters are to be dealt with in a prompt manner; and apart from this, it is advisable because, although the gasholders and test-meters have to be reverified every ten years, it materially lengthens the life of the instruments if they are well kept. The water should be emptied periodically, the bearings seen to, the cords and chains examined, and the gasholder bells drawn out of the water every night, care being taken that the cocks are all shut off, so as to avoid all possibility of the gas bubbling through the seal, with the danger of an explosion.

CHAPTER XII.

METER AND GOVERNOR TESTING.

799. *Meters to be Tested.*—The measuring apparatus authorised for use by "The Sales of Gas Act" having been described in Chapter XI, it remains to examine the clauses with reference to the meters to be tested.

By the 12th Clause of "The Sales of Gas Act," it is enacted that:

"No meter shall be stamped which shall be found by the inspector to register, or be capable of being made by any contrivance for that purpose, to register, or by increase or by decrease of the water in such meter, or by any other means practically prevented in good meters, to register quantities varying from the true standard measure of gas more than two *per centum* in favour of the seller, or three *per centum* in favour of the consumer; and every meter, whether stamped or unstamped, which shall be found by such inspector to register or be so capable of being made to register quantities varying beyond the limits aforesaid, shall be deemed incorrect within the meaning of this Act; and every meter which shall be found by any such inspector to measure and register quantities accurately, or not varying beyond the limits aforesaid, and shall be found incapable by any such means as aforesaid of being made to register quantities varying beyond the limits aforesaid, shall be considered to be correct, and be stamped as aforesaid in such manner and on such part of the meter as shall be specially directed by the authority appointing him, or in default of such direction as shall, in his opinion, best prevent fraud. Provided always, that every meter having a measuring capacity at one revolution or complete action of the meter of not less than five cubic feet, and having permanently marked upon it in some conspicuous place, the words 'without float,'

shall be stamped by the inspectors, if found correct, within the meaning of this Act, in all other respects except that it is capable of being made by abstraction of water to register incorrectly against the seller of gas, but it shall not be lawful after the time aforesaid to use in the sale of gas any such meter, when so stamped by the inspector, except by written agreement between the buyer and seller, specifying that this description of meter shall be used."

800. It will be seen from the above clause that two classes of wet meters are permitted to be stamped, viz., those which are incapable, and those which are capable of being made to register more than three per centum against the seller, on condition in respect to the latter that such meters shall be of such size as to pass at least five feet per complete action, and be distinctly marked with the words "without float." Many, if not most, of the meters "without float" will be of the kind called "station meters," from the fact of their construction being identical with those used in gas works and stations for measuring the gas manufactured.

801. Meters of the kind just mentioned, as well as all others of five or more cubic feet, measuring capacity per revolution which have no float must be inscribed as "without float," and these words are best put on a badge bearing the maker's name, number of the meter, and its capacity per revolution and per hour. The badge should be screwed on to the front of an iron-cased meter, and the inspector's stamp should cover one or more of the screw heads.

802. Every meter submitted for testing to an inspector appointed under the "Sales of Gas Act" must have affixed upon it a badge specifying "its measuring capacity at one revolution or complete action of the meter, and also the quantity per hour it is intended to measure in cubic feet, or multiples or decimal parts of a cubic foot."

803. On every ordinary wet meter there are two plugs, one on the upper part, called the charge-plug, and one at the

lower part of the case, called the syphon or overflow plug. Both these plugs are in front of the meter case.

804. In the index of every ordinary meter, wet or dry, there is a small metal drum, as in the wet meter, Fig. 95; or, in lieu of the drum, an additional circle on the index plate, as in the dry meter, Fig. 96. This drum or circle is divided into 2, 5, 10, or more, principal parts, representing as many cubic feet of measurement by the meter. It is by finding the quantity of gas, measured by the gasholder, which is re-

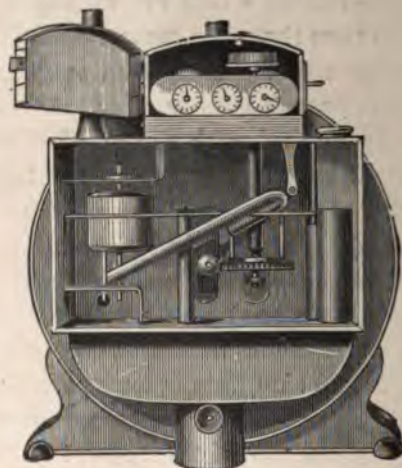


FIG. 95.—WET METER (FRONT REMOVED).

quired to pass through the meter in order to cause the index drum, or the pointer of the circle, to make an entire revolution, that the accuracy or the inaccuracy of the meter is determined.

805. It will be seen that the meters other than those "without float," are of two kinds, namely, dry and wet. The first of these are all of one type, as illustrated, but some of the cases are made of cast iron, although most dry meter cases are tin plate. Many attempts have been made to im-

prove the construction of a dry meter, but without success, and the instrument as it stands to-day is probably as perfect a dry meter as can be made. It must, however, be borne in mind that great differences can be obtained from a dry meter under different conditions of temperature, due to the flexible nature of the measuring chambers, and also to the liability of the slide-valves to get out of order. However, the

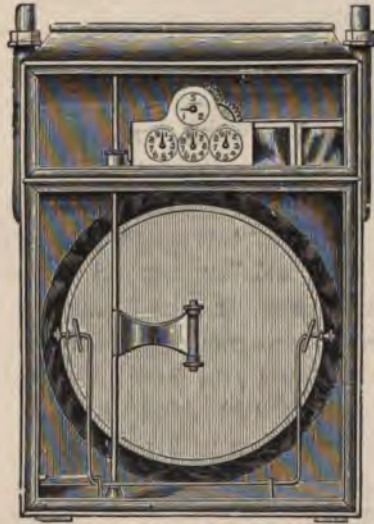


FIG. 96.—DRY METER (FRONT REMOVED).

dry meter as made to-day is sufficiently accurate for all ordinary purposes, and certainly is convenient.

806. A meter with two oscillating gasholders has recently been introduced by Mr. Greenall of Leeds, and it is claimed for this that it is absolutely invariable after being once set, that it can be worked at varying speeds without affecting its registration, and that it can be worked at a high speed without affecting its steadiness, and, therefore, can be used with a greater number of lights than a corresponding size of dry or wet meter. The system is not a new one, but Mr. Green-

all appears to have added details of construction which seem to have surmounted the difficulties which have probably stood in the way of the successful application of this type of meter on a practical scale. Fig. 97 illustrates this meter.

807. The wet meter is practically an exact measure, and those forms other than the meters "without float" are pro-

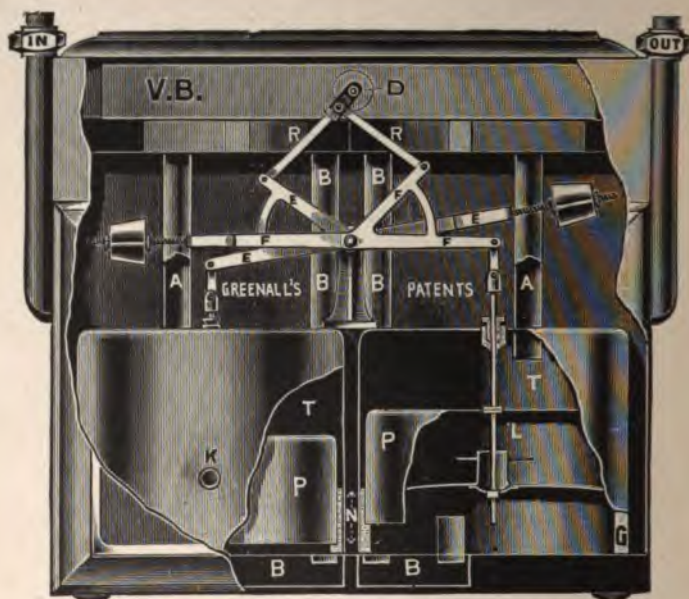


FIG. 97.—GREENALL'S METER (FRONT REMOVED).

vided with arrangements for keeping the height of the water, on which the accurate measurement depends, to its normal level. These devices are various, but those which are in ordinary use to-day are of three kinds, the spoon compensator, the "unvarying water-line," or cheese float, while the Warner & Cowan Drum provides for unvarying capacity with varying water-line. The first is an arrangement by which water is transferred from a storage chamber into the drum chamber, this being done by means of a spoon operated by a cam

fixed to the upright spindle of the meter. The water-level in the measuring chamber is thus kept constant. The second is an arrangement in which a semi-circular flat float balanced and weighed is pivoted so as to be further immersed as the water evaporates, thus restoring the original water-level. The third, the Warner & Cowan drum, consists of an ordinary drum with a smaller drum with reversed partitions placed inside it. The spout communicates with the inlet of both drums, and a depression in the water-level of the outer drum means a corresponding alteration in the water-level of the small drum. The compensating action is caused by the return of gas representing the capacity of the inner drum to the interior of the hollow cover of the outer drum, so that this gas is again measured. In an ordinary drum the lowering of the water level would mean that too much gas would be delivered, this excess gas in the Warner & Cowan drum being what is returned to be measured again.

808. The prepayment meter is an innovation which is not dealt with at present by the "Sales of Gas Act." A prepayment meter must be made so that the inspector can make the tests prescribed by the act, but the accuracy of the mechanism or its efficiency are not dealt with by him. The various important points, such as the soundness of the valve actuated by the mechanism, the correct delivery of the quantity per coin for which the meter is set, etc., are matters between the meter-maker, the gasmaker, and the consumer, so that the mechanism is not a factor to be taken into consideration at present by the inspector in testing this class of meter. It may not be without interest to know that the Board of Trade has been approached with a view to obtaining a reform of the "Sales of Gas Act," which would, *inter alia*, govern more closely the form of prepayment meters. The following is a clause from a bill introduced, though unsuccessfully,

into the House of Commons in 1900 by the London County Council:

“As soon as may be after the passing of this Act the Board of Trade shall, after holding an inquiry, approve a standard pattern or standard patterns of pre-payment meters and fittings for use in connection therewith, and shall fix for the use of such meters and fittings by the consumer such charges per thousand cubic feet of gas supplied by means thereof as they may think reasonable, having regard to the fair and proper cost of supplying such meters and fittings.”

809. With regard, then, to the testing of prepayment meters the operations are the same as with ordinary meters, as described later, but this should be borne in mind that especial care be taken with the soundness tests, and that the meters should be subjected to the “gauge” test, and under a pressure of from 6 to 8 inches. The reason for this is because if there is a small leak which would be unnoticeable under the ordinary test, and the gas from this leak passes into the mechanism chamber, the approach of a light when placing a coin in the meter might result in an explosion, and therefore, although not in any Act, the soundness test should be a stringent one.

810. The meters without float are wet meters of the kind designated in the trade as station meters, simply because they are in form and construction similar or identical to those employed in gas works; and for the larger sizes of these the test gasholder is useless and the test-meter must be used.

811. A station meter may, as to its case, be a simple cast iron cylinder, or a segmental cylinder, or a rectangular plain or ornamental cast iron tank, and the measuring capacity of its wheel may range from 5 feet per revolution up to 1000, or even 2000, cubic feet.

812. With all station meters the index is placed in the centre of the front, and the gas-inlet is in the centre of the

back; the gas outlet is also at the back and on one side of the inlet. Both the inlet and outlet openings are fitted with flanges for the attachment of the main pipes. The water-level of the meter is indicated on a gauge, similar to a boiler-gauge, affixed to the meter case, the glass tube of the gauge being protected by a sheath or other contrivance bearing the maker's number of the meter and the water-level mark or indicator. This sheath or contrivance should be stamped

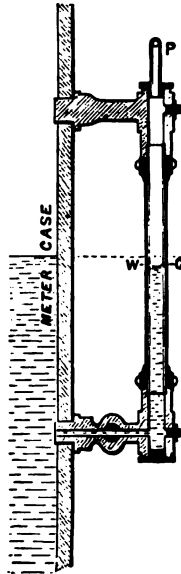


FIG. 98.—WATER LEVEL GAUGE.

by the inspector when such a meter is tested. Sometimes this gauge is so affixed to the meter as to be acted upon by the outlet pressure; it then shows the dead-level of the water, *i. e.*, the level when the meter is not working; but it is better to connect the gauge to the inlet, so that it is acted on by the inlet pressure of the gas, as in Fig. 98, where the pipe *P* is supposed to connect the gauge with the inlet, for

a consideration of the conditions under which a meter measures gas shows clearly that all meters to which gauges are affixed to indicate the water-level should have the water-line defined while the meter is in motion. The advantages are, that an inspector may test a wet meter at any convenient or possible rate of speed, marking the "working line" while it was in action; disconnect his testing apparatus, set the tested meter in full action, and then add the needful quantity of water to make it measure correctly. Further, an inspection of the water-line when the meter is in full action will at once show whether it is properly charged. The increased accuracy of registration on this system would in many instances amount possibly to 2 per cent. On the usual system the gas must be shut off from the meter before the water-level can be adjusted, causing at times much trouble and inconvenience.

813. Some meters are provided with a gauge similar in construction to that shown in Fig. 99. As shown, it is a box, rectangular in shape, attached to the meter case, and in communication with the interior thereof at a point x below the water-line. P is a pipe connecting the box with the inlet of the meter, so that the inlet pressure of the gas may act within the box. O is a vertical pipe screwed through the bottom of the box, and rising therein to the needful height for its top to coincide with the water-level. The bottom of O is sealed in a lute from which a pipe extends to a sink or drain. A meter which is provided with such a gauge as this cannot be overcharged with water, for any excess which may be run into the meter at once flows away through O . It is usual with large station meters in gas-works to keep a constant stream of water flowing into the meter, for the purpose of maintaining the water-level within the measuring wheel as equable as possible under varying rates of speed, and also for the purpose of keeping the water

in the meter in as clean a condition as possible. The box being subject to the inlet pressure, and the top of the pipe *O*, coinciding with the line of true measurement within the wheel, it will be apparent that when the working speed of the meter is increased the incoming water soon restores the true level, and that when the working speed slackens the increased rapidity of the outflow soon disposes of any excess.

814. Another form of water-level gauge is shown in Fig.

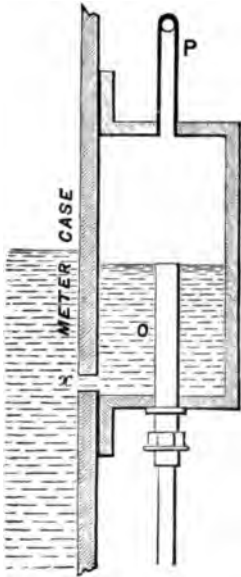


FIG. 99.—WATER LEVEL GAUGE.

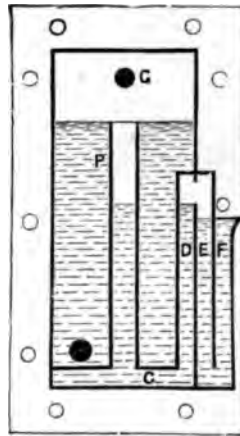


FIG. 100.—WATER LEVEL GAUGE.

100. It serves simply as a seal box, and is acted on by the outlet gas through the hole *G*, the water entering the box from the water-case through the lower hole. The pipe *P* is cut to the water-line and the water flows into *C*, thence through the channels *D E*, into the outer chamber *F*, and out at the spout. The advantage of this box is that an excess of water cannot be run off or syphoned out from *F*,

for, although it may be syphoned from *E F*, yet, as the water column is broken above *E*, the channels *D C* remain charged, thereby preserving the true level and preventing the escape of gas. There are several other forms of overflow water-level gauges, but those which have been described embrace the principles on which most are constructed.

815. The following are particulars of the capacities per hour and per revolution of dry and wet consumers and meters. The dry meters quoted are those by T. Glover & Co., Ltd. The capacity per revolution of a station meter is generally one-hundredth of its rate per hour:

Size of Meter	Capacity Per Hour Cubic Feet	Capacity per Revolution	
		Dry Cubic Feet	Wet Cubic Feet
Light.			
1	6	.0417	
2	12	.0833	.083
3	18	.125	.125
5	30	.166	.25
10	60	.333	.5
20	120	.5	1.0
30	180	.833	1.5
50	300	1.428	2.5
60	360	1.666	3.0
80	480	2.5	4.0
100	600	2.857	5.0
150	900	5.0	7.5
200	1200	6.666	10.0
250	1500	7.142	12.5
300	1800	8.33	15
400	2400	14.25	20
500	3000	20.0	25
600	3600		30
800	4800		40
1000	6000		50

TESTING BY HOLDER, OFFICIALLY.

816. Before a wet meter can be tested it must be properly charged with water. The manner of effecting this is as follows:

Remove the corks or stoppers which are usually placed in the inlet and outlet unions by the maker, or, better, take off the caps and linings. Set the meter, if of moderate size, on the proving-bench—or, if it be a large one, on the ground or floor—taking care that it stands perfectly level. Remove from ordinary meters the two plugs mentioned in a preceding paragraph and pour water through the socket from which the charge-plug is removed until a free flow ensues from the meter at the syphon socket. This is the only way by which a proper charge of water can be insured with many “consumer’s” wet meters. Leave the meter undisturbed, till dripping of water has ceased, replace the plugs, and the meter is ready for testing.

817. Dry meters require no other preparation for testing than the removal of the stoppers, or of the caps and linings, and the placing level on the bench.

818. Cones of suitable size to fit into the unions of the meters to be tested are to be screwed into the sockets on the ends of the flexible tubes of gasholders, etc. The cones on the gasholder pipes are to be inserted into the inlets, and the cones on the other pipes into the outlets of the meters. The junctions must then be made sound with a little putty pressed round the cones and upon the tops of the unions.

819. By Clause 13 of the “Sales of Gas Act” it is enacted that the following rules shall be observed by the inspectors in testing meters under the provisions of this act:

820. “Firstly, the meter shall be tested for soundness or leakage only, and not for percentage of error, when fixed on a horizontal base, and with the gas under a pressure equal to a column of water three inches high, with a light or lights consuming not more than one-twentieth part of its measuring capacity per hour marked thereon, nor less

than one-half of a cubic foot per hour, for all meters of a measuring capacity not exceeding one-hundredth cubic foot per hour, and not more than one-fortieth part of its said measuring capacity per hour, for all meters of any greater measuring capacity per hour than one hundred cubic feet; and all meters found to work under such test shall be deemed sound meters, and any meter found not to work under such test shall not be stamped."

821. "The meter to be tested for percentage of error shall be fixed on a horizontal base, and shall be tested at a pressure equal to a column of water five-tenths of an inch high, and passing the quantity of gas or atmospheric air per hour which shall be marked thereon as its measuring capacity per hour, and the water used in such testing, and the air of the room in which such testing shall be made shall be as nearly as practicable of the same temperature as the gas or air passed through the meter."

822. *Dry Meters.*—With these the testing operations are two in number, viz.:

Test for soundness.

Test for percentage, FAST OR SLOW.

823. *Wet Meters.*—With these the operations are three in number, viz.:

Test for soundness.

Test for percentage, FAST.

Test for percentage, SLOW.

824. The gasholder having been filled with gas from the service pipe connected with one of the cocks of the holder, the meter placed on the proving-bench, charged with water, and the plugs replaced if the meter be a wet one, and its inlet and outlet connected with the proper pipes in accordance with preceding paragraphs, the mode of performing the testing operations may now be illustrated.

825. *Test For Soundness.*—The act prescribes that the rates at which gas shall be passed through meters under this test shall be as follows:

1	Meters of a capacity to pass 10 cubic feet or less per hour.	Under this test are to pass	Half-a-cubic foot per hour.	
2	Meters of a capacity to pass from 10 to 100 feet per hour.	Under this test are to pass	1-20th	Of their measuring capacity per hour.
3	Meters of a capacity to pass more than 100 feet per hour.	Under this test are to pass	1-40th	

Half a cubic foot per hour is eighty-three ten-thousandths of a cubic foot per minute. In practical work this may be taken as one one-hundredth part of a cubic foot per minute, and for meters of the larger sizes the following rates per minute may be adopted as quite near enough :

CLASS 2.

Capacity cubic feet per hour.....	12½	15	20	30	40	50	60	80	100
Rates per minute in rooths of a cubic foot.....	1	1	2	3	3	4	5	7	8

CLASS 3.

Capacity cubic feet per hour.....	120	130	150	200	250	300	350	400
Rates in rooths of a cubic foot per min.	5	6	6	8	10	12	15	17

With, say, half-inch pressure on the gasholder pass sufficient gas through the meter to expel the air. When this is done shut off the gas and put the gasholder under three inches pressure (as ascertained from the gauge fixed to the holder). Close the outlet cock from the meter and turn on the gas to the meter. Then open the cock to burner in glazed case and adjust same to the proper rate as stated in act (see preceding paragraph). Should a leak exist in any part of the case (see par. 827) the meter must be rejected as unsound, as it must also be if the index fails to record the passage of gas. In this test it is sufficient to determine that the index moves; that is to say, that the pointer of the testing dial of index does not cease to travel regularly all the time.

826. To save time with small meters it is a good plan to have a few platinum or steatite jets with orifices of such size as to allow about half a cubic foot of gas to pass per hour under a three-inch pressure. These burners, if mounted on short stems or pillars provided with cocks, can be affixed to the outlets of the meters, and the adjustment to the required rate per hour quickly made. The gas passing from larger meters must be consumed at the float, or passed through the blow-off cock, as the heat given out would affect the temperature near the holders.

827. This is the only test for soundness prescribed by the "Sales of Gas Act," and is more effectual as a test for internal, rather than external, soundness. It is strongly recommended that a more stringent soundness test be applied to all meters, especially to prepayment meters, because a meter often is leaky but will not show the leak at first, at three inches pressure, though, perhaps, after it has been in use a little while the leak shows itself. The simplest, quickest, and most certain test is to connect the meter in the ordinary way, but to stop the outlet (after having expelled

the air from the meter and connections) and to observe the pressure on the wall water gauge or King's gauge, whichever is provided. If the cock from the gasholder is turned off (thus confining the pressure) it stands to reason that if there is a leak in the connections or in the meter it will form a vent for the pressure, and the gauge will go down. It should, therefore, be seen that after standing a few moments the gauge indication is constant, and that when the gas-holder cock is again turned on the level does not alter. If a leak shows itself in this way it may (if it cannot be traced by soapy water or the sense of smell) be searched for with the gas-torch (with the holder cock open) until located, and the meter rejected as unsound. Six or eight inches' pressure is not excessive for this test.

Test for Percentage.—Fast.

828. Having determined the soundness of the meter, turn off the gas, and if the same holder be used, replace as many of the weights as will reduce the pressure to half an inch. If the meter be a wet one remove the outlet connection of meter and take out the charge and syphon plugs; if any water flows out add more, and allow the excess to drain off. Replace the outlet connection; turn on the gas and adjust the burner and blow-off cock until the meter is working at its proper rate per hour. The regulation of the speed must in all cases be made by adjustment of the cocks beyond the *outlet* of the meter, and not by the gasholder cock. Observe the index drum, and as soon as a figured division is brought directly under the pointer turn off the gas. Refill the holder to the zero or other convenient point, and then pass gas through the meter until the index drum has made an entire revolution and the division started from is again

brought under the pointer, shut off the gas, and read on the gasholder scale how much gas has been used. As, in almost every case, a quantity more or less than an exact number of cubic feet will be used from the holder, while the meter will always record an exact number of cubic feet, it follows that the percentage of error can only be arrived at by a proportion. To save trouble in making calculations a table showing the percentages on various quantities as read off the gasholder scale is given at the end of the book (Appendix).

829. Thus, if the gasholder reading be 99 cubic feet and the meter record 100, the percentage of error will be 1.01 per cent fast: $99 : 100 :: 1 : 1.01$. If the registration of the meter does not exceed 2 per centum fast, or in favour of the seller, it is correct within the meaning of the act, and if it be a dry meter must be stamped, but if it be a wet meter it must then be submitted to another test. It should be noted that the percentage of error tables will not give figures which would serve as a basis for adjustment of a dispute as to figures of bill between gas maker and gas consumer, in the event of a meter being tested after use and found incorrect; but it gives the percentage of error as compared with the standard or correct measurement.

830. *Deficit or Slow Test.*—With the gasholder still in communication with the inlet of the meter, and the outlet of the latter delivering gas to one or more burners, draw off sufficient water by means of a syphon dipping into the meter, through its charge ring, in order to bring the float down, and thereby close the inlet valve. The instant this is affected the gas will cease to pass to the burners and the flames will be extinguished. Sometimes it may be most convenient to tilt the meter, and so draw off water from the lower socket. If this be done the meter must be restored to a horizontal position, and a gas-torch flame applied to the burner or

burners in order to make sure that no gas is passing. Next, with gas still turned on, pour water very gently into the meter, tapping same with finger the while, until the float rises, allowing gas to pass freely. Care must be taken not to add more water than is absolutely necessary to lift the float, and it is to assist the rising of the latter that the tapping is recommended. While performing this operation a small flame should be applied to the float burners, so that the instant the gas passes it may become apparent from its ignition.

831. Now take starting points on the index drum and on the gasholder scale, as in the former test, and register. If the meter be not more than 3 per cent. slow it will be correct within the meaning of the act, and must be stamped.

832. In the foregoing the process of testing with gas has been explained. Air can, however, be used without difficulty in the test for percentage of error fast, but not so easily in the test percentage of error slow, except when the measuring wheel is visible through the outlet of the meter. In such cases proceed as follows: After drawing off water, remove the outlet connection from the meter and nearly cover the outlet union with a small piece of glass. Turn on the air, pour in water, and gently tap, as before directed; while doing so look through the glass down upon the measuring wheel, and as soon as this is observed to move cease to add water; replace outlet connections and proceed to register as with gas. It will be necessary in all registration tests to correct results for temperature, as is seen from the following:

Corrections for Temperature.

833. There is both trouble and uncertainty in the making of corrections, when gas or air changes its temperature in

its passage from the holder through a meter, and it is advisable to use every possible care to maintain the testing-room at a uniform temperature, the water in the gasholder tanks, and the water with which wet meters are charged at the same temperature. Such care will demand less trouble, while it will ensure greater accuracy than is possible with calculated corrections.

834. It is usual to assume that the temperature of the gas or air at the outlet of the meter represents the temperature at which the gas or air has exerted its effect in working the meter. It has been suggested that it is doubtful whether this is the case, inasmuch as such assumption is based on the idea that the change in temperature is instantaneous. The experiments of Mr. Hartley tend to prove that the change is really so prompt that the outlet temperature fairly represents that within the meter.

835. It will be realised, however, that the conditions under which the testing of ordinary gas meters are conducted are such as to render scientific accuracy impossible. It is inconvenient to attach a thermometer immediately to the outlet of each meter, and if this were done the rough work of a testing-room would scarcely permit of the use of thermometers of a sufficiently sensitive, and therefore delicate character; but still, as much care as possible should be taken to ascertain the temperature of the gas or air employed as it leaves the gasholder, and as it afterwards leaves the meter.

836. The following table by the then Astronomer Royal was published in a Parliamentary paper, No. 339, Session 1861, and shows the percentage increase or dilation of the volume of gas above its volume at 31.4° Fahr. when in contact with water, and saturated with aqueous vapour for given temperatures, and its examination will show that between 44.17° and 67.43° , the difference in volume approximates closely to 1 per cent. for every 4 degrees difference in ten

perature, the law being that all aeriform bodies expand $\frac{1}{480}$ th part of their volume at 32° Fahr. for every Fahr. degree increase of temperature.

Temperature in Fahrenheit's Scale.	Percentage of Dilatation.	Temperature in Fahrenheit's Scale.	Percentage of Dilatation.	Temperature in Fahrenheit's Scale.	Percentage of Dilatation.
31.40	0	54.33	$5\frac{1}{2}$	74.30	11
33.54	$\frac{1}{2}$	56.24	6	75.94	$11\frac{1}{2}$
35.70	1	58.12	$6\frac{1}{2}$	77.23	12
37.84	$1\frac{1}{2}$	60.02	7	78.81	$12\frac{1}{2}$
39.91	2	62.00	$7\frac{1}{2}$	80.40	13
42.05	$2\frac{1}{2}$	63.77	8	81.94	$13\frac{1}{2}$
44.17	3	65.63	$8\frac{1}{2}$	83.44	14
46.22	$3\frac{1}{2}$	67.43	9	84.88	$14\frac{1}{2}$
48.25	4	69.18	$9\frac{1}{2}$	86.39	15
50.32	$4\frac{1}{2}$	70.90	10	87.83	$15\frac{1}{2}$
52.36	5	72.60	$10\frac{1}{2}$	89.20	16

Hence, for ordinary purposes and for ordinary temperatures corrections may be made on the basis that 4° Fahr. increase or decrease in the temperature of air or gas over water produce 1 per cent. difference in the volume of such air or gas.

837. With gas issuing from a meter at a different temperature than that which it has in the gasholder:

RULE.—Multiply the number of cubic feet and parts delivered from the holder by the number of degrees of difference in temperature and by 0.0025 and, (a) if the gas from the meter be *higher* in temperature, *add* the product to the quantity indicated by the gasholder; (b) if the gas be of lower temperature at the outlet of the meter, *subtract* the product from the gasholder reading. Example:

Temperature at holder	(a) 59°	(b) 61°
Temperature at meter	61°	59°
Difference at meter	2° higher	2° lower
Meter registration	5 c. ft.	5 c. ft.
Gasholder indication	4.9 c. ft.	4.9 c. ft.
$4.9 \times 2 \times .0025$	.025 = nearly = .025	
Volume passed through meter	4.925 c. ft.	4.875 c. ft.
The nearest numbers in the table are	4.93 c. ft.	4.88 c. ft.
The meter would appear as	1.42 fast	2.46 fast
But for gasholder indication, would appear as	2.04 fast	2.04 fast

838. A simpler, but less accurate, method of correcting for temperature, is as follows:

RULE.—With gas issuing from the meter at a *higher* temperature than from the holder, *subtract* the percentage difference in volume from the percentage of error as per table, and when the gas issues from the meter at a *lower* temperature, *add* the percentage difference to the percentage of error of the table. Ex.:

Gasholder reading.....4.9 cu.ft..... 4.9
 Temperature at holder 59° 61°
 " " meter 61° 59°
 Differences = half per cent.

Per cent. error by table ...	2.04 fast	2.04 fast
Subtract	.5	add .5
	1.54 fast	2.54 fast
Error by previous rule....	1.42	2.46
	1.12	0.08
Differences per cent. by second rule	.12	0.08

Testing by Meter, Officially.

839. There are three conditions under which a meter may be presented for verification by the aid of a test-meter :

1. Fixed in position for use, complete with service pipes, but having had no gas delivered into it.
2. Fixed and in actual use.
3. Unfixed and standing in a yard or shop.

The test-meter must be placed on a firm, level base as near the meter to be tested as possible. The fittings are placed upon it, it is filled with water after having been levelled, and the water-line adjusted. As pointed out in paragraph 759, the water-line must be adjusted to the marked level when the meter is working at the rate at which it will be used. If it is being used at above its normal speed, a little water will probably have to be added, which can be done through a seal or syphon funnel screwed into the charge socket, or by other obvious means. A little practice will be needed to make an adjustment of the level while the meter is working, owing to the oscillation of the water, but the true line is easily fixed by observing that the range of oscillation is equal on each side; that is, above and below the marked line.

840. Dealing with the first condition referred to in paragraph 839, and assuming that it is a station-meter which is to be tested, the following description of the diagram, Fig. 101, and the accompanying remarks will render the arrangement intelligible. *A* represents the back of the test-meter, *B* the back of the station-meter to be tested, *C* is the inlet pipe of the latter, with a valve at *D*. The outlet pipe is *E*, having a valve at *F*, while *G* is another valve to serve as a bye-pass. All these valves are supposed to be, and must be, closed when the test is made. *H* is a pipe connecting the inlet pipe, below the valve *D*, to the inlet of the test-meter, but the gas may, of course, be obtained from any other convenient source of

for the discharge of the gas. If the meter be in the open air the pipe is not needed, but the cock may be screwed into the upper part of *E*. *M* is an overflow water-box, similar to that shown in Fig. 99, while *P* is a pressure gauge on the pipe connecting *M* to the inlet of the meter. *N* is a water-level gauge, similar to that represented in Fig. 98, but subject, as is also the attached gauge *P*, to the pressure of the outlet gas. *TT* are thermometers inserted in the respective outlets of the two meters. *W* is a pipe through which water is delivered into the station-meter at a point near to its base, while *Y* is a main cock by which the water may be wholly discharged from the meter when needful. The station-meter may be charged with water to the heights indicated on the gauges through the pipe *W*, or from a water-service pipe attached to the cock *Y*, or in any other convenient way; it must, however, be observed that while being so charged the meter must be in communication with the atmosphere through *L* or some other point. The best way to test the registration of a station-meter is to remove the index and to attach a stout wire, by a screw or by soldering, to the key-wheel (which in nearly all station-meters is in the centre of the index pot), so that the free end of the wire projects a little beyond the edge of the index pot, a pencil or fine chalk mark serving as the starting (and stopping) point. The accuracy of the index train may be determined by calculation after counting the number of teeth in each wheel and pinion, and also by a final revolution or two of the drum after the index is refitted.

Test for Soundness.

841. Pass gas through both meters until the whole or the greater part of the air is expelled from them. During this operation adjust the speed of the test-meter by its outlet

cock to the rate desired, and note the extent to which the cock is opened.

842. Close the cock *L* and as soon as the gas in both meters is compressed to the extent due to the acting pressure, the index of the test-meter should remain motionless. If it continues so for the space of a few minutes, the station-meter and its connections may be considered sound; but if any movement takes place, leaks must be sought for in the connections and about the meter case, by the aid of the sense of smell alone; unless the leak be very trifling and the meter has had gas passing through it for a long time, or sufficiently long to cause the measuring-wheel to make several revolutions, for the application of a flame might lead to an explosion, which would be of so serious a nature with a large meter that the slightest risk of it should be scrupulously avoided. Of course, no danger of an explosion will ensue from the application of a light to a small hole in a meter which has had gas, and gas only, passing through it for a long time, if the inlet opening be much larger than the outlet, and the gas be supplied under a good pressure; but in testing it is most convenient generally to reduce the inlet to the large meter by the test-meter cock, as stated in the last paragraph. Sometimes the leaks may be discovered by the bubbles produced when fluid paint, water, or other liquid is brushed over the joints and connections.

Registration Test.

843. When the meter and connections have been proved to be gas-tight, the test for registration may be made in one of the following ways, the first being usual, but far less reliable than the second:

844. *First Method.*—Pass gas through the meters until the temporary pointer (see end of par. 840) reaches a pencil or other mark made on the edge of the index pot, or the

index indicates an exact number of cubic feet, viz., 10, 100, 1000, or any other whole number, then close the cock of the test-meter and set its index (by turning the large hand backwards) to zero, re-open the test-meter cock to the required extent and allow the gas to flow until the temporary pointer or the index of the station-meter shows that at least two revolutions of its measuring-wheel have been made, then instantly close the cock of the test-meter. Alter the water-level within the station-meter and re-test as many times as may be needful until it agrees with the test-meter.

845. *Second Method.*—Close the cock *L*, open the test-meter cock to the required extent. The gas will enter both meters. Set the test-meter to zero or nearly so. Make a mark for a zero point a little in advance of the temporary pointer of the station-meter, or fix upon some figure on its dial in advance of the dial-pointer, and note what the index registration will be when the figure fixed upon is reached. Open the cock *L*. Both meters will commence working. Observe the test-meter index, and note its registration the instant an assistant gives a signal that the index or pointer of the station-meter has reached the figure or mark fixed upon. Continue the flow of gas until the assistant signals the completion of a revolution of the station-meter, and then instantly close the cock of the test-meter and note the index of the latter; the difference between the first and last readings, if the temperature within both meters be the same, equals the capacity of the station-meter at the existing water-line.

Example:

With meter of 50 cubic feet normal capacity per rev.

Test Meter index at the end of the test.....	55.3
“ “ “ “ commencement “	4.4

Capacity of station-meter	50.9
---------------------------	------

Showing its water-line to be low, and its registration *slow* to the extent of 1.77 per cent. (see percentage table).

846. If the temperature of the gas at the outlets of the two meters differs, the indicated volume must be corrected, and the calculation can only be conveniently made on the volume indicated by the test-meter.

RULE.—Calculate the difference in the volume of gas due to change of temperature (par. 837). Add the difference to the indication of the test-meter if the gas issues from the station-meter at the *highest* temperature. Deduct the difference from the indication of the test-meter if the gas issues from the station-meter at the lowest temperature.

Example:

Gas outlet Station-Meter.....	65°
“ “ Test “	61°
Difference	4°
Ex.—Gas outlet Test-Meter	58°
“ “ Station “	54°
Difference	4°

Four degrees can be taken as being equal to 1% in volume (par. 836).

Now 1 per cent. on 50.9 is .509, and this has in the first example to be added, making 51.409 as the capacity of the station-meter. In the second case it has to be deducted, leaving 50.391 as the capacity. The correction can also be made by a rule in paragraph 838.

847. When a meter is fixed and has been at work for some time it will be fair to assume that the connections are sound; hence, unless there are special reasons to the contrary, the “soundness test” may be omitted and the test-meter may be attached to a pipe from the outlet of the station-meter, so that the gas shall first pass through the latter meter. The verification should be made after the manner described, the

flow of the gas being wholly controlled by the test-meter cock, instead of being so in part by the cock *L*, Fig. 101.

848. If a meter has to be verified under the third condition (par. 839), adjust it to a perfect level by the aid of wedges, blocks, or other convenient means. Be careful also that the meter stands upright, that is to say, that the centre line indicated by punch or other marks on the front plate is vertical; this must be determined by the aid of a plumb line. Next charge the meter with water of, as nearly possible, the same temperature as the surrounding atmosphere. Close the inlet of the meter (making a perfectly sound joint with yarn and lead putty) with a blank flange provided in its centre with a short nosepiece of 1 or $1\frac{1}{2}$ pipe. Close the outlet in the same way, but the blank flange must be provided with a cock answering to *L* (Fig. 101), and with a socket to receive a thermometer. Place the test-meter near to the meter to be tested, and proceed as directed.

Verification of a Dry Meter with a Wet Test-Meter.

849. In the verification of large dry meters the test-meter should generally be applied to the outlet. The internal soundness of the dry meter can in this way only be determined by passing gas at a low rate for some time and noting the indications of both indexes. If these agree the verification may be proceeded with.

Suggested Amendment of "Sales of Gas Act."

850. In giving below the remarks made by Mr. Hartley twenty years ago, the writer wishes to point out that none of the reforms expected by Mr. Hartley have come to pass, and that Mr. Hartley's sanguine anticipations have not been fulfilled. The question of testing indexes has recently become prominent again, and it appears to the writer that the

question as regards dry meter indexes could be solved in the following manner:

(a) Each index to bear the number and name of maker of the meter upon its dial, and to be sent, apart from the meter, to the Local Inspector for examination.

(b) The index to be then tested (there are many devices by which this could be done quickly), and the junction of one of the pillars with the back frame and the dial sealed.

(c) The index to be returned to the maker ready to be placed in the meter bearing its number.

If the indexes were sent in batches it does not appear that much trouble would be entailed, and while it is obvious that the method suggested would not guard against fraud, it is not necessary that it should do so, all that is required being a method of examination that would prevent errors. The index of a wet meter could be sealed in the same manner, the correctness of its train of wheels being ascertained. In the case of wet meters, however, the matter is complicated by the fact that the upright spindle (which gears from the shaft of the measuring wheel to the small testing drum of index) also forms the gearing between this testing drum and the first circle of the index. It would obviously be a difficult matter to ensure a particular spindle being used with a particular index, and in the case of a dry meter this difficulty does not exist, as the train of wheels from testing dial onwards is complete in the index itself. The testing of the index of a wet meter could, therefore (it appears to the writer), only effect the correctness of the train of wheels, and not that of the first circle of the dial.

851. Mr. Hartley's above referred to remarks are as follows:

“(a) The present Act has always been regarded as imperfect, and successive Governments have been urged to amend it or to supersede it by a new Act. In 1871 the

author, in a paper read by him at the meeting of the B. A. Gas Managers, advocated the re-verification of meters at Moderate Intervals of Time—The Compulsory adoption of the Act by Local Authorities and its Application in every Borough and City in the Kingdom—The Testing of Indexes—The Formulation of Precise Rules to be observed in Meter Testing.

"(b) The Board of Trade have for a long time had the "Sales of Gas Act" under consideration and will, without doubt, get a new Act passed at an early date. The author has reason to believe that its provisions will render necessary the periodical re-verification of gas meters. Suggestions have been made that the Act should be adopted and put into operation by Local authorities, who, from lapse of time, are barred by the present Act from doing so. It should compel any local authority who have adopted, or who may adopt the Act, to put it completely into operation, there being some few places where, although the Act has been adopted, it is very imperfectly carried into effect. Besides this, the Board of Trade should, and may probably, take power itself to appoint an Inspector in a district, if deemed necessary, and to provide him with the requisite apparatus.

"(c) Specific rules should be drawn up for meter-testing, but whether these should be contained in the new Act or be issued as instructions by the Board of Trade is a question for consideration. It has also been suggested that the number of tests should be increased, and that meters in future should be subjected to a test for soundness, as at present; for registration under different pressures and at different speeds, as well as for *steadiness* of lights when working at full speed, and finally that the indexes shall be tested when separated from the meters. The author has advocated the testing of indexes when fixed to the meter, but fancies that "the powers that be" see some objections to this plan. Under the present Act no power is *actually given* to an inspector to reject a meter for *unsteadiness of lights*, but he certainly would hesitate to stamp such a meter, while it would be objected to, both by buyer and seller of gas.

"(d) It is to be hoped also that provision will be made for the testing of large meters at low speeds and low pressures, for with meters fixed for use, and for the testing of which the test-meter must be employed, high pressures

and full speed are impossible, as full speed is also, even when a gasholder is employed. Unless some provision be made in this respect it will be really illegal to use a legalised instrument, and impossible, in fact, to make any test whatever which would comply with the law. Such is the state of matters now, and such they would remain.

"(e) Many meters have of necessity been tested at low speed and at low pressure, and although such meters are, without doubt, correct, yet if disputes were to arise between the buyer and seller of gas, and a question were raised in a Court of Law as to the legality of the mode of testing, it can scarcely be doubtful what the issue would be."

851A. *The standardisation of meter unions* is a point which for many years past has been earnestly desired, so as to remove the inconvenience that arises from the non-interchangeability of caps and bosses. The sizes given by the Standards Department of the Board of Trade will be found in paragraph 761. The matter of a standard screw-thread, however, is one that covers a much wider ground than that of gas fittings, and while it seems impossible that the same character of thread should be used for all purposes, it is highly desirable that each particular class could be served by a uniform thread. The matter is, at the moment this is written, engaging the serious attention of the Standards Department of the Board of Trade, and it is to be hoped that the labours of Mr. Chaney, the Warden, and his assistant, Mr. S. F. Read, will be crowned with success.

Information as to Books, Forms, etc.

852. *Forms of Books and Certificates.*—It will be found advisable to adopt some special system of book-keeping in a meter-testing station, while certain forms of certificates are also required. Mr. Alfred Spencer, the head of the Public Control Committee of the London County Council, under whose guidance the testing of meters in London is

particularly well organised, has kindly placed at the writer's disposal all information as to how the question of organization is dealt with by his department. The following list of books can, of course, be modified to suit different circumstances, while the forms of certificates are well known and require no description.

Register of gas meters tested.

Ledger, containing accounts of meter-makers for stamping fees.

Weekly statement book of fees received and amounts outstanding.

Receipt book of fees received.

Delivery book, showing the summarised particulars of meters removed from the testing offices, with the carman's signature.

Day book.

Register of incorrect indices.

853. The fees for stamping meters are as follows, meters rejected more than once being charged again for each subsequent testing. The charge for testing *in situ* is double the ordinary fee, plus expenses, this applying to consumers' meters only and not to station-meters:

TABLE OF STAMPING FEES FOR CONSUMERS' METERS.

Size.	Wet.	Dry.	Size.	Wet.	Dry.
1 Light..	..	6d	100 Light	5/	2/
2 " ..	6d	6d	120 "	..	3/
3 " ..	6d	6d	150 "	7/	5/
5 " ..	6d	6d	200 "	10/	6/
10 " ..	1/	1/	250 "	12/	7/
20 " ..	1/	1/	300 "	15/	8/
30 " ..	1/	1/	400 "	20/	14/
50 " ..	2/	1/	500 "	25/	20/
60 " ..	3/	1/	600 "	30/	22/
80 " ..	4/	2/	800 "	40/	25/
			1,000 "	50/	33/

Meter and Governor Testing at a Gas Works.

855. The methods of meter-testing already described are those in official testing stations under the "Sales of Gas Act." In many gas works, however, it is the custom to test meters independently, and in such cases the procedure described above is followed. The testing of automatic meters on gas works is, however, on different lines, because a gas manager wants to be assured of the reliability of the mechanism which, as before stated, is not examined by an official inspector. The testing of the mechanism for free passage of coins, non-liability to injury by bent coins, freedom from possibility of fraudulent handling, etc., will vary according to the mechanism tested, but for two important points, viz, soundness of valve and proper delivery of quantity of gas per coin for which the meter is set, can always be carried out in the same manner.

856. *The test for valve soundness* should be made by letting a coin deliver naturally (and without turning the mechanism by the hand) its quantity of gas, and seeing, firstly, that on insertion of another coin towards the end of the duty of the first coin the valve does not shut off, and secondly, that at the end of the duty of the coin the valve shuts off dead sound, both with high pressure and with low pressure.

857. *The test for quantity per coin* is easily made by using a wet meter modified by the addition of a large dial showing 100 feet divided into feet, and even one-half foot, and connecting this with a slot meter and running air at a suitable pressure through them both. The dial will indicate the quantity the slot meter passed, and this method secures a continuous test without refilling holder, and without the use of gas. The test-meter described can be made from any tin-cased wet meter by the addition of a simple dial, and will

give as accurate results as a more elaborate test or experimental meter.

858. *Governor Testing.*—It is often necessary in a gas works to test, for consumption and governing point, the regulators used in street lamps with flat flame and incandescent burners. For this purpose the gasholder can be utilised, as

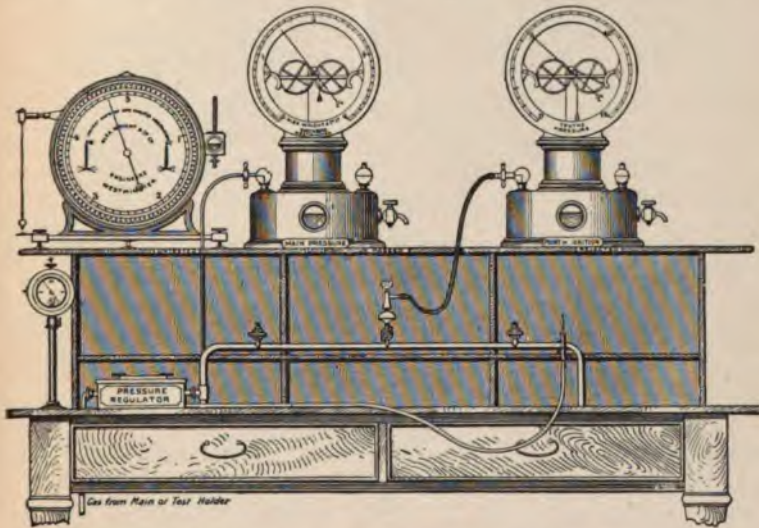


FIG. 102.—GOVERNOR TESTING APPARATUS.

it affords means of delivering gas at any required pressure, and to make a proper test, especially of governors for incandescent burners, it is advisable to use in conjunction with the holder an apparatus similar to that illustrated in Fig. 102. It will be seen that two King's gauges are provided, one showing pressure up to 4 or 6 inches, and the other showing pressure up to $1\frac{1}{2}$ inches.

859. The apparatus is connected up to the holder with, say, 4" pressure, and the governor to be tested is screwed upon one of the cocks on the rail, the pressure actually sup-

plied to the governor being *regulated* by the double diaphragm governor shown fitted on the table, and indicated on one of the King's gauges. If the governor is for a flat-flame burner the cone is taken off and a tee with a burner tip of same size as that on cone placed above the governor, the side of tee being connected with rubber tube to the second King's gauge.

860. This gauge will then show the "point of ignition" pressure, which should be reached when the pressure at which the governor comes into action is applied, and remain constant when this inlet pressure is increased.

861. *With a flat flame burner* the consumption is taken at the pressure at which the governor comes into action, the inlet pressure being noted, and the increase of this should cause no appreciable alteration in the indication of the second King's gauge, and in this way the recording of consumptions at various pressures is obviated.

862. *With an incandescent burner* the following facts must be borne in mind: There is a certain pressure at which the nipple of an incandescent burner will give the desired consumption which is most suitable for the mantle. Take, for instance, a No. 4 Kern burner; it may be found (and this will vary with the gas used) that at fifteen-tenths pressure a consumption of 4 feet per hour is obtained without any governor. What is desired, therefore, is a governor which will allow 4 feet per hour to pass through the *burner* (not through the governor alone) until the pressure of fifteen-tenths below the governor is reached, and will at this point also show fifteen-tenths pressure at the *point of issue*, and which will keep this latter constant, however much the inlet-pressure, as shown on the first King's gauge, is increased.

863. What is in effect required is a governor which will

not take up any pressure in its working, and in which the gasways (through the float, disc or other device) are *not larger* than that of the nipple of the incandescent burner, for if this is not so the governor will be put out of action when surmounted by the burner.

864. It will be seen that the observation of the constancy point of ignition pressure (taken by a tee under the nipple) and the testing of the governor with the nipple above it affords a convenient, accurate, and rapid means of proving that the incandescent burner is being kept to its most efficient point, whatever the variation in inlet pressure.

865. It is quite an error to test a governor by itself and think that, if correct, the combination of governor and incandescent burner will be correct. Generally speaking, a volumetric or atmospheric leather diaphragm governor will be found most suitable for use with incandescent burners, but a carefully made metal governor will, if suitably selected, answer very well.

866. The figures below make the question of point of ignition (or point of issue) pressure clear:

No. 4 Kern burner tested:

Consumption: 4 feet per hour with 15-10ths pressure under the nipple, without any governor and light satisfactory at this point.

Governor screwed on to rail, surmounted by burner, which is intercepted just below the nipple by a tee connected to the second King's gauge; mantle not required.

Following results found:

	<i>Inlet Pressure.</i>	<i>Point of Ignition Pressure.</i>
Governor A	$\frac{1}{8}$ ths.	$\frac{1}{8}$ ths.
	$\frac{2}{8}$ ths.	$\frac{1}{8}$ ths.
	$\frac{3}{8}$ ths.	$\frac{1}{8}$ ths.
	$\frac{4}{8}$ ths.	$\frac{1}{8}$ ths.

The above is a good governor and can be passed.

		(B)	(C)
Governor <i>B</i> and <i>C</i>	$\frac{1}{10}$ ths.	$\frac{1}{10}$ ths.	$\frac{1}{10}$ ths.
	$\frac{2}{10}$ ths.	$\frac{1}{10}$ ths.	$\frac{1}{10}$ ths.
	$\frac{3}{10}$ ths.	$\frac{1}{10}$ ths.	$\frac{2}{10}$ ths.

The above are bad governors. In (b) the consumption decreases as pressure increases; in (c) the consumption increases with pressure.

867. In a Kern burner the light yield increases with the pressure, and it may not be desired to check the consumption of gas. In an incandescent "C" burner, or one of similar type, the light yield decreases with the pressure, and it is quite necessary to automatically regulate the consumption of gas if the full economy of this type of burner is to be developed. In either case, if it is required to govern the consumption it should be borne in mind:

(a) It is useless to test the governor apart from the burner.

(b) Having found the pressure at which burner gives its best result, it is only necessary to see that this pressure at point of ignition is maintained, however the inlet pressure varies.

(c) It is thus useless to take a long series of tedious consumption tests, because

(d) If the point of ignition pressure is constant, the consumption is also constant.

APPENDIX.

TABLE A.

RULES TO FACILITATE THE CALCULATIONS NECESSARY IN THE DETERMINATION OF THE ILLUMINATING POWER OF GAS.

Rule 1. Take 10 readings of bar at intervals of one minute, commencing at beginning of test and finishing at ninth minute, reversing disc after the fifth reading. Record the readings with the mean of same.

Rule 2. Observe the time in which the candles burn 40 grains of sperm. Refer to Table C (or where special dial to clock is provided, to the latter), for corrected consumption of sperm in 10 minutes. Multiply mean of readings by this figure.

Rule 3. Divide the last obtained sum by 20 or point to the left a decimal place and divide by 2.

Rule 4. Observe rate per hour of consumption of gas, and if it is not 5 feet per hour refer to Table B for a multiplier for correction. Multiply the result obtained after carrying out rule 3 by this multiplier.

Rule 5. Observe temperature by thermometer in meter, also the pressure of atmosphere by barometer. Refer to Table D and extract therefrom the tabular number for the respective temperature and pressure and divide result obtained after carrying out rule 4 by this tabular number.

The result is the corrected illuminating power for the test.

Rule 6. Average the three tests and the mean is the corrected illuminating power for the day.

TABLE B.

Gas—C. ft. per hour	4.7	4.75	4.8	4.85	4.9	4.95	5.0
Multiplier . .	1.06	1.05	1.04	1.03	1.02	1.01	0.0
Gas—C. ft. per hour	5.05	5.1	5.15	5.2	5.25	5.3	5.35
Multiplier . .	.990	.980	.971	.961	.952	.943	.934

TABLE C.

2 CANDLES. — Consumpt of 40 grains of Sperm in Min. Secs.	2 CANDLES. — Consumpt in 10 Minutes. — Grains.	Consumpt for one Candle per hour. — Grains.	2 CANDLES. — Consumpt of 40 grains of Sperm in Min. Secs.	2 CANDLES. — Consumpt in 10 Minutes. — Grains.	Consumpt for one Candle per hour. — Grains.
10 31	38.03	114.1	9 58	40.13	120.4
10 30	38.1	114.29	9 57	40.2	120.6
10 29	38.16	114.58	9 56	40.26	120.8
10 28	38.21	114.65	9 55	40.33	121.
10 27	38.31	114.8	9 54	40.4	121.21
10 26	38.33	115.	9 53	40.47	121.41
10 25	38.40	115.2	9 52	40.54	121.62
10 24	38.46	115.38	9 51	40.6	121.82
10 23	38.52	115.56	9 50	40.67	122.01
10 22	38.58	115.75	9 49	40.74	122.22
10 21	38.64	115.92	9 48	40.81	122.44
10 20	38.71	116.12	9 47	40.88	122.65
10 19	38.77	116.31	9 46	40.95	122.86
10 18	38.83	116.5	9 45	41.02	123.07
10 17	38.9	116.69	9 44	41.09	123.27
10 16	38.96	116.88	9 43	41.16	123.49
10 15	39.02	117.07	9 42	41.23	123.71
10 14	39.08	117.26	9 41	41.3	123.92
10 13	39.15	117.45	9 40	41.38	124.13
10 12	39.21	117.64	9 39	41.45	124.35
10 11	39.28	117.84	9 38	41.52	124.56
10 10	39.34	118.03	9 37	41.59	124.78
10 9	39.41	118.22	9 36	41.66	125.
10 8	39.47	118.41	9 35	41.74	125.21
10 7	39.54	118.61	9 34	41.81	125.43
10 6	39.6	118.81	9 33	41.88	125.65
10 5	39.66	119.	9 32	41.96	125.87
10 4	39.73	119.2	9 31	42.03	126.09
10 3	39.8	119.4	9 30	42.1	126.31
10 2	39.87	119.6	9 29	42.18	126.53
10 1	39.93	119.8	9 28	42.25	126.75
10 0	40.0	120.	9 27	42.32	126.97
9 59	40.06	120.2	9 26	42.4	127.2

TABLE D.

BAR.	THR. 32°	34°	36°	38°	40°	42°	44°	46°	48°	50°	52°	54°	56°	58°
28.0	998	993	988	984	979	974	970	965	960	956	951	946	942	937
28.1	1002	997	993	988	983	978	973	969	964	959	955	951	945	941
28.2	1006	1001	996	991	986	981	977	972	967	963	958	953	949	944
28.3	1009	1004	1000	995	990	985	980	976	971	966	961	957	952	947
28.4	1012	1007	1002	998	993	988	984	979	974	970	965	960	955	951
28.5	1016	1011	1006	1001	997	992	987	983	978	973	968	964	959	954
28.6	1020	1015	1010	1005	1001	995	991	986	981	977	972	967	962	958
28.7	1023	1018	1013	1009	1004	999	994	990	985	980	975	970	966	961
28.8	1027	1022	1017	1012	1007	1003	998	993	988	984	979	974	969	964
28.9	1031	1026	1021	1016	1011	1006	1001	997	992	987	982	977	973	968
29.0	1034	1029	1024	1019	1014	1010	1005	1000	995	990	986	981	976	971
29.1	1038	1033	1028	1023	1018	1013	1008	1004	999	994	989	984	979	975
29.2	1041	1036	1031	1026	1021	1017	1012	1007	1002	997	992	988	982	978
29.3	1045	1040	1035	1030	1025	1020	1015	1011	1006	1001	996	991	986	981
29.4	1048	1043	1038	1033	1028	1024	1019	1014	1009	1004	999	995	990	985
29.5	1052	1046	1041	1036	1032	1027	1022	1018	1013	1008	1003	998	993	988
29.6	1055	1050	1045	1040	1036	1031	1026	1021	1016	1011	1006	1001	996	992
29.7	1059	1054	1049	1044	1039	1034	1029	1025	1019	1015	1010	1005	1000	995
29.8	1063	1058	1053	1048	1043	1038	1033	1028	1023	1018	1013	1008	1003	998
29.9	1066	1061	1056	1051	1046	1041	1036	1031	1026	1022	1017	1012	1007	1002
30.0	1070	1065	1060	1055	1050	1045	1040	1035	1030	1025	1020	1015	1010	1005
30.1	1073	1068	1063	1058	1053	1048	1043	1038	1033	1029	1024	1019	1014	1009
30.2	1076	1071	1066	1062	1057	1052	1047	1042	1037	1032	1027	1022	1017	1012
30.3	1080	1075	1070	1065	1060	1055	1050	1045	1040	1036	1030	1025	1020	1015
30.4	1084	1079	1074	1069	1064	1059	1054	1049	1044	1039	1034	1029	1024	1019
30.5	1087	1082	1077	1072	1067	1062	1057	1052	1047	1042	1037	1032	1027	1022
30.6	1090	1085	1080	1075	1071	1066	1061	1056	1051	1046	1041	1036	1031	1026
30.7	1094	1089	1084	1079	1074	1069	1064	1059	1054	1049	1044	1039	1034	1029
30.8	1098	1093	1088	1083	1078	1073	1068	1063	1058	1053	1048	1043	1037	1032
30.9	1101	1096	1091	1086	1081	1076	1071	1066	1061	1056	1051	1046	1041	1036
31.0	1105	1100	1095	1090	1085	1080	1075	1070	1065	1060	1055	1049	1044	1039

TABLE D.—Continued.

BAR.	THR. 60°	62°	64°	66°	68°	70°	72°	74°	76°	78°	80°	82°	84°
28.0	932	927	922	917	912	907	902	897	892	887	881	875	870
28.1	936	930	926	921	916	911	905	900	895	890	884	879	873
28.2	939	934	929	924	919	914	909	904	898	893	887	882	876
28.3	942	937	932	928	922	917	912	907	902	896	891	885	880
28.4	946	941	936	931	926	921	915	910	905	900	894	888	883
28.5	949	944	939	934	929	924	919	914	908	903	897	892	886
28.6	953	947	943	938	932	927	922	917	912	906	901	895	889
28.7	956	951	946	941	936	931	925	920	915	909	904	898	893
28.8	959	954	949	944	939	934	929	924	918	913	907	901	896
28.9	963	958	953	948	942	937	932	927	921	916	910	905	899
29.0	966	961	956	951	946	941	935	930	925	919	914	908	903
29.1	969	964	959	954	949	944	939	933	928	923	917	911	906
29.2	973	968	963	958	952	947	942	937	931	926	920	914	909
29.3	976	971	966	961	956	950	945	940	935	929	923	918	912
29.4	980	975	969	964	959	954	949	943	938	932	927	921	915
29.5	983	978	973	968	962	957	952	947	941	936	930	924	919
29.6	986	981	976	971	966	960	955	950	944	939	933	927	922
29.7	990	985	980	974	969	964	959	953	948	942	937	931	925
29.8	993	988	983	978	972	967	962	957	951	946	940	934	928
29.9	997	991	986	981	976	970	965	960	954	949	943	937	932
30.0	1000	995	990	985	979	974	968	963	958	952	946	941	935
30.1	1003	998	993	988	983	977	972	966	961	955	950	944	938
30.2	1007	1002	996	991	986	980	975	970	964	959	953	947	941
30.3	1010	1005	1000	995	989	984	978	973	968	962	956	950	945
30.4	1014	1008	1003	998	993	987	982	976	971	965	959	954	948
30.5	1017	1012	1006	1001	996	990	985	980	974	969	963	957	951
30.6	1020	1015	1010	1005	999	994	988	983	977	972	966	960	954
30.7	1024	1018	1013	1008	1003	997	992	986	981	975	969	963	957
30.8	1027	1022	1017	1011	1006	1000	995	990	984	978	972	967	961
30.9	1031	1025	1020	1015	1009	1004	998	993	987	982	976	970	964
31.0	1034	1029	1023	1018	1013	1007	1002	996	991	985	979	973	967

TABLE E.—TESTINGS FOR ILLUMINATING POWER.

(See Tables A, B, C and D.)

		DATE.			
Time.....8.2 p.m.		8.30 p.m.		9 p.m.	
Barometer 29.0		29.0		29.1	
Thermometer 50° F.		54° F.		52° F.	
Tabular No. (Table D)...990		.981		.989	
Time of burning 40 grs.					
of Sperm.....10m. 21s.		9m. 45s.		9m. 50s.	
See Table C for Sperm					
Consumption in 10 m.					
(for Rule 2) ...38.64 grs.		41 grs.		40.67 grs.	
Rate of Gas cons.4.9 cu. ft.		4.9 cu. ft.		5.0 cu. ft.	
See Table B for multi-					
plier (for Rule 4)...1.02		1.02		1.0	
Reverse disc.	Observations taken at intervals of 1 min.	Reverse disc.	Observations taken at intervals of 1 min.	Reverse disc.	Observations taken at intervals of 1 min.
	1st min.....7.8		1st min...8.1		1st min...8.2
	2d.....7.8		2d.....8.2		2d.....8.3
	3d.....8.1		3d.....8.1		3d.....8.3
	4th.....8.2		4th.....8.3		4th.....8.4
	5th.....8.3		5th.....8.0		5th.....8.3
	6th.....8.5		6th....8.5		6th.....8.3
	7th.....8.6		7th.....8.2		7th.....8.2
	8th.....8.4		8th.....8.2		8th.....8.1
	9th.....8.3		9th.....8.1		9th.....8.1
	10th.....8.6		10th.....8.3		10th.....8.1
Rule 1	Mean...8.2 6	Rule 1	Mean...8.2	Rule 1	Mean...8.2 3
Rule 2	3 8.6 4	Rule 2	4 1	Rule 2	4 0.6 7
	3 3 0 4		8 2		5 7 6 1
	4 9 5 6		3 2 8		4 9 3 8
	6 6 0 8				0
	2 4 7 8				3 2 9 2
Rule 3	2)3 1.9 1	Rule 3	2)3 3.6 2	Rule 3	2)3 3.4 7 1 4 1
	1 5.9 5		1 6.8 1		1 6.7 3
Rule 4	1.0 2		1.0 2		1.0
	3 1 9 0		3 3 6 2		
	0		0		
	1 5 9 5		1 6 8 1		
Rule 5	990)16.2 6 9 0(16.43	Rule 5	981)17.1 4 6 2(17.47	Rule 5	989)16.7 3(16.91
	99		98 1		98 9
	63 6		73 3 6		68 4 0
	59 4		68 6 7	Mean of Tests	59 3 4
	4 2 9		4 6 9 2		9 0 6 0
	3 9 6		3 9 2 4		8 9 0 1
	3 3 0		7 6 8 0	1st...16.43	1 5 9 0
	2 9 7		68 6 7	2d...17.47	98 9
				3d...16.91	
				3)50.81	
				16.93	
Corrected illumi- nating power, 16.43		Corrected illumi- nating power, 17.47		Corrected illumi- nating power, 16.91	

TABLE F.—PHOTOMETRICAL TABLES

FOR CALCULATING THE ILLUMINATING POWER OF GAS FROM THE
USUAL OBSERVATIONS.

BY J. A. COOMBS.

EXPLANATION OF TABLES.

In Table I., the numbers = the logs. of the number of candles.

In Table II., $G = \log. \frac{5}{c}$, where c = consumption of gas per hour.

In Table III., $S = \log. \frac{10}{t}$, where t = time of burning 40 grs. of sperm.

In Table IV., $T = \log. \frac{460 + t}{17.64(30 - a)}$

In Table V., $B = \log. \frac{460 + 60}{17.64(h - 0.518)}$

where h = height of barometer in inches, t the temperature of the gas
and a the tension of aqueous vapour at t .

TO USE THE TABLES.

Add together the numbers corresponding to the various data of the
experiment; discard any integral figures in the sum, and find the cor-
rected value from Table I.

EXAMPLE.—Suppose the average readings = 8.56 with two candles—
i.e., uncorrected illuminating power = 17.12. Suppose also the meter
lost two divisions in 10 minutes—i.e., consumption of gas = 4.98 cubic
feet—and the candles burnt 40 grs. in 10 min. 15 sec. Temperature
of gas = 55°, and barometer at 29.8 inches. Then—

17.12 = 2335 by Table I.	55 = 9945 by Table IV.
4.98 = 0017 " " II.	29.8 = 0029 " " V.
10.15 = 9893 " " III.	
	2219
	Corrected value = 16.67 by Table I.

TABLE I.

Sperm Candles.							Sperm Candles.						
	14	15	16	17	18	19		14	15	16	17	18	19
.00	1461	1761	2041	2304	2553	2788	.50	1614	1903	2175	2430	2672	2900
.02	1467	1767	2047	2310	2558	2792	.52	1620	1909	2180	2435	2676	2905
.04	1474	1772	2052	2315	2562	2797	.54	1626	1915	2185	2440	2681	2909
.06	1480	1778	2057	2320	2567	2801	.56	1632	1920	2191	2445	2686	2914
.08	1486	1784	2063	2325	2572	2806	.58	1638	1926	2196	2450	2690	2918
.10	1492	1790	2068	2330	2577	2810	.60	1644	1931	2201	2155	2695	2923
.12	1498	1796	2074	2335	2582	2815	.62	1649	1937	2206	2460	2700	2927
.14	1504	1801	2079	2340	2586	2819	.64	1655	1942	2212	2465	2704	2931
.16	1511	1807	2084	2345	2591	2824	.66	1661	1948	2217	2470	2709	2936
.18	1517	1813	2090	2350	2596	2828	.68	1667	1953	2222	2475	2714	2940
.20	1523	1818	2095	2355	2601	2833	.70	1673	1959	2227	2480	2718	2945
.22	1529	1824	2100	2360	2605	2838	.72	1679	1965	2232	2485	2723	2949
.24	1535	1830	2106	2365	2610	2842	.74	1685	1970	2238	2490	2728	2953
.26	1541	1836	2111	2370	2615	2847	.76	1691	1976	2243	2494	2732	2958
.28	1547	1841	2117	2375	2620	2851	.78	1697	1981	2248	2499	2737	2962
.30	1553	1847	2122	2380	2625	2856	.80	1703	1986	2253	2504	2742	2967
.32	1559	1853	2127	2385	2629	2860	.82	1708	1992	2258	2509	2746	2971
.34	1565	1858	2233	2390	2634	2865	.84	1714	1998	2263	2514	2751	2975
.36	1572	1864	2138	2395	2639	2869	.86	1720	2003	2269	2519	2755	2980
.38	1578	1870	2143	2400	2643	2874	.88	1726	2008	2274	2524	2760	2984
.40	1584	1875	2148	2405	2648	2878	.90	1732	2014	2279	2529	2765	2989
.42	1590	1881	2154	2410	2653	2882	.92	1738	2019	2284	2533	2769	2993
.44	1596	1886	2159	2415	2658	2887	.94	1744	2025	2289	2538	2774	2997
.46	1602	1892	2164	2420	2662	2891	.96	1749	2030	2294	2543	2778	3002
.48	1608	1898	2170	2425	2667	2896	.98	1755	2036	2299	2548	2783	3006

TABLE II.

Correction for Consumption of Gas.		Correction for Consumption of Gas.		Correction for Consumption of Gas.		Correction for Consumption of Gas.		Correction for Consumption of Gas.	
Rate of Gas per Hour.	G.	Rate of Gas per Hour.	G.	Rate of Gas per Hour.	G.	Rate of Gas per Hour.	G.	Rate of Gas per Hour.	G.
C. F.		C. F.		C. F.		C. F.		C. F.	
4.75	0223	.85	0132	.95	0044	.05	9957	.15	9872
.76	0214	.86	0123	.96	0035	.06	9948	.16	9863
.77	0205	.87	0114	.97	0026	.07	9940	.17	9855
.78	0195	.88	0105	.98	0017	.08	9931	.18	9846
.79	0186	.89	0097	.99	0009	.09	9923	.19	9838
.80	0177	.90	0088	5.00	0000	.10	9914	.20	9830
.81	0168	.91	0079	.01	9991	.11	9905	.21	9821
.72	0159	.92	0070	.02	9983	.12	9897	.22	9813
.83	0150	.93	0061	.03	9974	.13	9889	.23	9805
.84	0141	.94	0052	.04	9965	.14	9880	.24	9796

TABLE III.

Correction for Consumption of Sperm.		Correction for Consumption of Sperm.		Correction for Consumption of Sperm.		Correction for Consumption of Sperm.		Correction for Consumption of Sperm.	
Time Burn'g 40 Grs.	S.	Time Burn'g 40 Grs.	S.	Time Burn'g 40 Grs.	S.	Time Burn'g 40 Grs.	S.	Time Burn'g 40 Grs.	S.
M. S.		M. S.		M. S.		M. S.		M. S.	
9 30	0223	50	0073	10	99	30	9788	50	9652
31	0215	51	0066	11	99	31	9781	51	9646
32	0208	52	0058	12	99	32	9774	52	9639
33	0200	53	0051	13	990	33	9767	53	9632
34	0192	54	0044	14	990	34	9761	54	9626
35	0185	55	0036	15	9893	35	9754	55	9619
36	0177	56	0029	16	9886	36	9747	56	9612
37	0170	57	0022	17	9879	37	9740	57	9606
38	0162	58	0014	18	9872	38	9733	58	9599
39	0155	59	0007	19	9865	39	9726	59	9593
40	0147	10 0	0000	20	9858	40	9720	11 0	9586
41	0140	1	9993	21	9851	41	9713	1	9580
42	0132	2	9986	22	9844	42	9706	2	9573
43	0125	3	9978	23	9837	43	9699	3	9566
44	0117	4	9971	24	9830	44	9693	4	9560
45	0110	5	9964	25	9823	45	9686	5	9554
46	0103	6	9957	26	9816	46	9679	6	9547
47	0095	7	9950	27	9809	47	9672	7	9540
48	0088	8	9942	28	9802	48	9666	8	9534
49	0080	9	9935	29	9795	49	9659	9	9527

TABLE IV.

Correction for Temperature of Gas.		Correction for Temperature of Gas.		Correction for Temperature of Gas.		Correction for Temperature of Gas.		Correction for Temperature of Gas.	
Temp. Fahr.	T.	Temp. Fahr.	T.	Temp. Fahr.	T.	Temp. Fahr.	T.	Temp. Fahr.	T.
84	0292	74	0162	64	0044	54	9934	44	9830
83	0278	73	0150	63	0033	53	9924	43	9820
82	0265	72	0138	62	0022	52	9913	42	9810
81	0251	71	0126	61	0011	51	9902	41	9800
80	0238	70	0114	60	0000	50	9892	40	9790
79	0226	69	0102	59	9988	49	9882	39	9780
78	0213	68	0090	58	9977	48	9871	38	9770
77	0200	67	0078	57	9966	47	9861	37	9760
76	0187	66	0067	56	9955	46	9850	36	9750
75	0175	65	0056	55	9945	45	9840	35	9740

TABLE V.

Correction for Barometric Pressure.		Correction for Barometric Pressure.		Correction for Barometric Pressure.		Correction for Barometric Pressure.		Correction for Barometric Pressure.	
Bar. Ins.	B.	Bar. Ins.	B.	Bar. Ins.	B.	Bar. Ins.	B.	Bar. Ins.	B.
30.95	9862	.45	9933	29.95	0007	.45	0081	28.95	0157
.90	9869	.40	9940	.90	0014	.40	0089	.90	0165
.85	9876	.35	9948	.85	0022	.35	0096	.85	0172
.80	9883	.30	9955	.80	0029	.30	0104	.80	0180
.75	9890	.25	9963	.75	0036	.25	0111	.75	0188
.70	9897	.20	9970	.70	0044	.20	0119	.70	0195
.65	9905	.15	9977	.65	0051	.15	0126	.65	0203
.60	9912	.10	9985	.60	0059	.10	0134	.60	0211
.55	9919	.05	9992	.55	0066	.05	0142	.55	0218
.50	9926	.00	0000	.50	0074	.00	0149	.50	0226

TABLE G.—RAPID READING PHOTOMETER.

Correction of Readings for Gas Consumption.

Readings on Bar	CONSUMPTION (RATE PER HOUR)												
	4.7	4.75	4.8	4.85	4.9	4.95	5	5.05	5.1	5.15	5.2	5.25	5.3
15	15.9	15.75	15.6	15.45	15.3	15.15	15	14.85	14.7	14.56	14.41	14.28	14.14
15.5	16.43	16.27	16.12	15.96	15.81	15.65	15.5	15.34	15.19	15.05	14.89	14.75	14.61
16	16.96	16.8	16.64	16.48	16.32	16.16	16	15.84	15.68	15.53	15.37	15.23	15.08
16.5	17.49	17.32	17.16	16.99	16.83	16.66	16.5	16.33	16.17	16.02	15.85	15.7	15.55
17	18.02	17.85	17.68	17.51	17.34	17.17	17	16.83	16.66	16.5	16.33	16.18	16.03
17.5	18.55	18.37	18.2	18.025	17.85	17.67	17.5	17.32	17.15	16.99	16.81	16.66	16.5
18	19.08	18.9	18.72	18.54	18.36	18.18	18	17.82	17.64	17.47	17.29	17.13	16.97
18.5	19.61	19.42	19.24	19.05	18.87	18.68	18.5	18.31	18.13	17.96	17.77	17.61	17.44
19	20.14	19.95	19.76	19.57	19.38	19.19	19	18.81	18.62	18.44	18.25	18.08	17.91
19.5	20.67	20.47	20.28	20.08	19.89	19.69	19.5	19.3	19.11	18.93	18.73	18.56	18.38
20	21.2	21	20.8	20.6	20.4	20.2	20	19.8	19.6	19.42	19.22	19.04	18.86
20.5	21.73	21.52	21.32	21.11	20.91	20.7	20.5	20.29	20.09	19.9	19.70	19.51	19.33
21	22.26	22.05	21.84	21.63	21.42	21.21	21	20.79	20.58	20.39	20.18	19.99	19.80
21.5	22.79	22.57	22.36	22.14	21.93	21.71	21.5	21.28	21.07	20.87	20.66	20.46	20.27
22	23.32	23.1	22.88	22.66	22.44	22.22	22	21.78	21.56	21.36	21.14	20.94	20.74
22.5	23.85	23.62	23.4	23.17	22.95	22.72	22.5	22.27	22.05	21.84	21.62	21.42	21.21
23	24.38	24.15	23.92	23.69	23.46	23.23	23	22.77	22.54	22.33	22.10	21.89	21.68
23.5	24.91	24.67	24.44	24.2	23.97	23.73	23.5	23.26	23.03	22.81	22.58	22.37	22.16
24	25.44	25.2	24.96	24.72	24.48	24.24	24	23.76	23.52	23.3	23.06	22.84	22.63
24.5	25.97	25.72	25.48	25.23	24.99	24.74	24.5	24.25	24.01	23.78	23.54	23.32	23.1
25	26.5	26.25	26	25.75	25.5	25.25	25	24.75	24.5	24.27	24.02	23.8	23.57
25.5	27.03	26.77	26.52	26.26	26.01	25.75	25.5	25.24	24.99	24.76	24.5	24.27	24.04
26	27.56	27.3	27.04	26.78	26.52	26.26	26	25.74	25.48	25.24	24.98	24.75	24.51
26.5	28.09	27.82	27.56	27.29	27.03	26.76	26.5	26.23	25.97	25.73	25.46	25.22	24.98
27	28.62	28.35	28.08	27.81	27.54	27.27	27	26.73	26.46	26.21	25.94	25.7	25.46
27.5	29.15	28.87	28.6	28.32	28.05	27.77	27.5	27.22	26.95	26.70	26.42	26.18	25.93
28	29.68	29.4	29.12	28.84	28.56	28.28	28	27.72	27.44	27.18	26.9	26.65	26.4
28.5	30.21	29.92	29.64	29.35	29.07	28.78	28.5	28.21	27.93	27.67	27.38	27.13	26.87
29	30.74	30.45	30.16	29.87	29.58	29.29	29	28.71	28.42	28.15	27.86	27.60	27.34
29.5	31.27	30.97	30.68	30.38	30.09	29.79	29.5	29.2	28.91	28.64	28.34	28.08	27.81
30	31.8	31.5	31.2	30.9	30.6	30.3	30	29.7	29.4	29.13	28.83	28.56	28.29

TABLE H.—16-CANDLE GAS.

TABLE giving the ILLUMINATING POWER OF GAS as calculated from Observations of the Rate of Consumption required to yield the Light of 16 Candles, and from Readings of the Barometer, Thermometer, and Refractive Tables, of the Aerothermometer. The observed time of passage through the meter of one-sixth of a cubic foot of gas is to be found in the left-hand column; and the Aerothermometer Reading or Tabular Number in the top lines. In the corresponding line and column is found the Illuminating Power.

Aerothermometer...		.9300 .9400 .9500 .9600 .9700 .9800 .9900 1.0000 1.0100 1.0200 1.0300 1.0400 1.0500 1.0600 1.0700 1.0800 1.0900 1.1000 1.1100 1.1200																					
Tabular Number.		1.0751 1.0644 1.0533 1.0422 1.0311 1.0200 1.0100 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000																					
Minute. Seconds.																							
1	44	12.90	13.03	13.17	13.31	13.45	13.59	13.73	13.87	14.01	14.14	14.28	14.42	14.56	14.70	14.84	14.98	15.11	15.25	15.39	15.53	15.67	15.81
2	45	13.02	13.16	13.30	13.43	13.57	13.71	13.85	13.99	14.13	14.27	14.41	14.55	14.69	14.83	14.97	15.11	15.25	15.39	15.53	15.67	15.81	15.95
3	46	13.14	13.29	13.43	13.57	13.71	13.85	13.99	14.13	14.27	14.41	14.55	14.69	14.83	14.97	15.11	15.25	15.39	15.53	15.67	15.81	15.95	16.09
4	47	13.27	13.41	13.55	13.70	13.84	13.98	14.12	14.27	14.41	14.55	14.69	14.83	14.97	15.11	15.25	15.39	15.53	15.67	15.81	15.95	16.09	16.23
5	48	13.39	13.54	13.68	13.82	13.97	14.11	14.26	14.40	14.54	14.69	14.83	14.97	15.11	15.25	15.39	15.53	15.67	15.81	15.95	16.09	16.23	16.37
6	49	13.52	13.66	13.81	13.95	14.10	14.24	14.39	14.53	14.68	14.82	14.97	15.11	15.25	15.39	15.53	15.67	15.81	15.95	16.09	16.23	16.37	16.51
7	50	13.64	13.79	13.93	14.08	14.23	14.37	14.52	14.67	14.81	14.96	15.11	15.25	15.39	15.54	15.69	15.84	15.98	16.13	16.28	16.42	16.57	16.71
8	51	13.76	13.91	14.06	14.21	14.36	14.51	14.66	14.81	14.95	15.10	15.24	15.39	15.53	15.68	15.83	15.98	16.12	16.27	16.41	16.56	16.70	16.85
9	52	13.89	14.04	14.19	14.34	14.49	14.63	14.78	14.93	15.08	15.23	15.38	15.53	15.68	15.83	15.98	16.13	16.28	16.43	16.57	16.72	16.86	17.01
10	53	14.01	14.16	14.31	14.46	14.61	14.77	14.92	15.07	15.22	15.37	15.52	15.67	15.82	15.97	16.12	16.27	16.42	16.57	16.72	16.87	17.02	17.17
11	54	14.14	14.29	14.44	14.59	14.74	14.90	15.05	15.20	15.35	15.50	15.64	15.79	15.95	16.10	16.25	16.40	16.55	16.70	16.85	17.00	17.15	17.30
12	55	14.26	14.41	14.57	14.72	14.87	15.03	15.18	15.33	15.49	15.64	15.79	15.95	16.10	16.25	16.40	16.55	16.70	16.85	17.00	17.15	17.30	17.45
13	56	14.38	14.54	14.69	14.85	15.00	15.16	15.31	15.47	15.62	15.78	15.93	16.09	16.24	16.39	16.54	16.69	16.84	17.00	17.15	17.30	17.45	17.60
14	57	14.51	14.66	14.82	14.98	15.13	15.29	15.44	15.60	15.75	15.91	16.07	16.22	16.38	16.53	16.68	16.83	16.99	17.14	17.29	17.44	17.59	17.74
15	58	14.63	14.79	14.95	15.10	15.26	15.42	15.58	15.73	15.89	16.05	16.21	16.36	16.52	16.67	16.82	16.98	17.13	17.29	17.44	17.59	17.74	17.89
16	59	14.76	14.91	15.07	15.23	15.39	15.55	15.71	15.87	16.03	16.18	16.34	16.50	16.65	16.81	16.96	17.11	17.27	17.42	17.58	17.73	17.88	18.03
17	0	15.00	15.17	15.33	15.49	15.65	15.81	15.97	16.13	16.29	16.45	16.61	16.77	16.92	17.08	17.23	17.38	17.54	17.69	17.84	18.00	18.15	18.30
18	1	15.13	15.29	15.45	15.62	15.78	15.94	16.10	16.27	16.43	16.59	16.75	16.91	17.07	17.23	17.38	17.54	17.69	17.85	18.00	18.15	18.31	18.46
19	2	15.25	15.42	15.58	15.74	15.91	16.07	16.24	16.40	16.56	16.73	16.89	17.06	17.22	17.38	17.54	17.70	17.86	18.02	18.18	18.33	18.49	18.64
20	3	15.38	15.54	15.71	15.87	16.04	16.20	16.37	16.53	16.70	16.86	17.03	17.19	17.35	17.51	17.67	17.83	18.00	18.16	18.32	18.48	18.64	18.79
21	4	15.50	15.67	15.83	16.00	16.17	16.33	16.50	16.67	16.83	17.00	17.17	17.33	17.50	17.67	17.83	18.00	18.17	18.33	18.50	18.66	18.82	18.98
22	5	15.62	15.79	15.96	16.13	16.30	16.46	16.63	16.80	16.97	17.14	17.30	17.47	17.64	17.81	17.98	18.14	18.31	18.48	18.64	18.81	18.97	19.14
23	6	15.75	15.92	16.09	16.26	16.43	16.59	16.76	16.93	17.10	17.27	17.44	17.61	17.78	17.95	18.12	18.29	18.46	18.63	18.80	18.97	19.14	19.31
24	7	15.87	16.04	16.21	16.38	16.55	16.73	16.90	17.07	17.24	17.41	17.58	17.75	17.92	18.09	18.26	18.43	18.60	18.77	18.94	19.11	19.28	19.45
25	8	16.00	16.17	16.34	16.51	16.68	16.86	17.03	17.20	17.37	17.54	17.72	17.89	18.06	18.23	18.40	18.58	18.75	18.92	19.09	19.26	19.43	19.60
26	9	16.12	16.29	16.47	16.64	16.81	16.99	17.16	17.33	17.50	17.68	17.85	18.03	18.20	18.37	18.54	18.71	18.89	19.06	19.23	19.40	19.57	19.74
27	10	16.24	16.42	16.59	16.77	16.94	17.12	17.29	17.47	17.64	17.82	17.99	18.17	18.34	18.51	18.68	18.86	19.03	19.20	19.37	19.54	19.71	19.88
28	11	16.37	16.54	16.72	16.90	17.07	17.25	17.42	17.60	17.78	17.95	18.13	18.30	18.48	18.66	18.83	19.01	19.18	19.36	19.53	19.70	19.87	20.04
29	12																						

75

Time in Seconds.

75 × Tabular Number.

Time in Seconds.

7.5 × Tabular Number.

Illuminating Power = Aerothermometer Reading × Time in Seconds

TABLE H₁.—14-CANDLE GAS.

TABLE giving the ILLUMINATING POWER OF GAS as calculated from Observations of the Rate of Consumption required to yield the Light of 14 Candles, and from Readings of the Barometer, Thermometer, and References' Tables, or of the Aerothermometer. The observed time of passage through the Meter of one-sixth of a cubic foot of gas is to be found in the left-hand column; and the Aerothermometer Reading or Tabular Number in the top lines. In the corresponding line and column is found the Illuminating Power.

Aerothermometer... Tabular Number:	930	940	950	960	970	980	990	1-000	1-010	1-020	1-030	1-040	1-050	1-060	1-070	1-080	1-090	1-100	1-110	1-120
Minute, Seconds.	1-075	1-064	1-053	1-042	1-031	1-020	1-010	1-000	1-010	1-020	1-030	1-040	1-050	1-060	1-070	1-080	1-090	1-100	1-110	1-120
1	11-28	11-40	11-53	11-65	11-77	11-89	12-01	12-13	12-25	12-37	12-50	12-62	12-74	12-86	12-98	13-10	13-22	13-35	13-47	13-59
2	11-39	11-51	12-04	12-16	12-28	12-40	12-52	13-04	13-16	13-28	13-40	13-52	14-04	14-16	14-28	14-40	14-52	15-04	15-16	15-28
3	11-50	12-02	12-15	12-27	12-39	12-51	13-03	13-15	13-27	13-39	13-51	14-03	14-15	14-27	14-39	14-51	15-03	15-15	15-27	15-39
4	12-01	12-13	12-26	12-38	12-50	13-02	13-14	13-26	13-38	13-50	14-02	14-14	14-26	14-38	14-50	15-02	15-14	15-26	15-38	15-50
5	12-12	12-24	12-37	12-49	13-01	13-13	13-25	13-37	13-49	14-01	14-13	14-25	14-37	14-49	15-01	15-13	15-25	15-37	15-49	15-61
6	12-23	12-35	12-48	13-00	13-12	13-24	13-36	13-48	14-00	14-12	14-24	14-36	14-48	15-00	15-12	15-24	15-36	15-48	15-60	15-72
7	12-34	12-46	12-59	13-11	13-23	13-35	13-47	13-59	14-11	14-23	14-35	14-47	14-59	15-11	15-23	15-35	15-47	15-59	16-11	16-23
8	12-45	12-57	13-10	13-22	13-34	13-46	13-58	14-10	14-22	14-34	14-46	14-58	15-10	15-22	15-34	15-46	15-58	16-10	16-22	16-34
9	12-56	13-08	13-21	13-33	13-45	13-57	14-09	14-21	14-33	14-45	14-57	15-09	15-21	15-33	15-45	15-57	16-09	16-21	16-33	16-45
10	13-07	13-19	13-32	13-44	13-56	14-08	14-20	14-32	14-44	14-56	15-08	15-20	15-32	15-44	15-56	16-08	16-20	16-32	16-44	16-56
11	13-18	13-30	13-43	13-55	14-07	14-19	14-31	14-43	14-55	15-07	15-19	15-31	15-43	15-55	16-07	16-19	16-31	16-43	16-55	17-07
12	13-29	13-41	13-54	14-06	14-18	14-30	14-42	14-54	15-06	15-18	15-30	15-42	15-54	16-06	16-18	16-30	16-42	16-54	17-06	17-18
13	13-40	13-52	14-05	14-17	14-29	14-41	14-53	15-05	15-17	15-29	15-41	15-53	16-05	16-17	16-29	16-41	16-53	17-05	17-17	17-29
14	13-51	14-03	14-16	14-28	14-40	14-52	15-04	15-16	15-28	15-40	15-52	16-04	16-16	16-28	16-40	16-52	17-04	17-16	17-28	17-40
15	14-02	14-14	14-27	14-39	14-51	15-03	15-15	15-27	15-39	15-51	16-03	16-15	16-27	16-39	16-51	17-03	17-15	17-27	17-39	17-51
16	14-13	14-25	14-38	14-50	15-02	15-14	15-26	15-38	15-50	16-02	16-14	16-26	16-38	16-50	17-02	17-14	17-26	17-38	17-50	18-02
17	14-24	14-36	14-49	15-01	15-13	15-25	15-37	15-49	16-01	16-13	16-25	16-37	16-49	17-01	17-13	17-25	17-37	17-49	18-01	18-13
18	14-35	14-47	15-00	15-12	15-24	15-36	15-48	16-00	16-12	16-24	16-36	16-48	17-00	17-12	17-24	17-36	17-48	18-00	18-12	18-24
19	14-46	14-58	15-11	15-23	15-35	15-47	15-59	16-11	16-23	16-35	16-47	16-59	17-11	17-23	17-35	17-47	17-59	18-11	18-23	18-35
20	14-57	15-09	15-22	15-34	15-46	15-58	16-10	16-22	16-34	16-46	16-58	17-10	17-22	17-34	17-46	17-58	18-10	18-22	18-34	18-46
21	15-08	15-20	15-33	15-45	15-57	16-09	16-21	16-33	16-45	16-57	17-09	17-21	17-33	17-45	17-57	18-09	18-21	18-33	18-45	18-57
22	15-19	15-31	15-44	15-56	16-08	16-20	16-32	16-44	16-56	17-08	17-20	17-32	17-44	17-56	18-08	18-20	18-32	18-44	18-56	19-08
23	15-30	15-42	15-55	16-07	16-19	16-31	16-43	16-55	17-07	17-19	17-31	17-43	17-55	18-07	18-19	18-31	18-43	18-55	19-07	19-19
24	15-41	15-53	16-06	16-18	16-30	16-42	16-54	17-06	17-18	17-30	17-42	17-54	18-06	18-18	18-30	18-42	18-54	19-06	19-18	19-30
25	15-52	16-04	16-17	16-29	16-41	16-53	17-05	17-17	17-29	17-41	17-53	18-05	18-17	18-29	18-41	18-53	19-05	19-17	19-29	19-41
26	16-03	16-15	16-28	16-40	16-52	17-04	17-16	17-28	17-40	17-52	18-04	18-16	18-28	18-40	18-52	19-04	19-16	19-28	19-40	19-52
27	16-14	16-26	16-39	16-51	17-03	17-15	17-27	17-39	17-51	18-03	18-15	18-27	18-39	18-51	19-03	19-15	19-27	19-39	19-51	20-03
28	16-25	16-37	16-50	17-02	17-14	17-26	17-38	17-50	18-02	18-14	18-26	18-38	18-50	19-02	19-14	19-26	19-38	19-50	20-02	20-14
29	16-36	16-48	17-01	17-13	17-25	17-37	17-49	18-01	18-13	18-25	18-37	18-49	19-01	19-13	19-25	19-37	19-49	20-01	20-13	20-25
30	16-47	16-59	17-12	17-24	17-36	17-48	18-00	18-12	18-24	18-36	18-48	19-00	19-12	19-24	19-36	19-48	20-00	20-12	20-24	20-36
31	16-58	17-10	17-23	17-35	17-47	17-59	18-11	18-23	18-35	18-47	18-59	19-11	19-23	19-35	19-47	19-59	20-11	20-23	20-35	20-47
32	17-09	17-21	17-34	17-46	17-58	18-10	18-22	18-34	18-46	18-58	19-10	19-22	19-34	19-46	19-58	20-10	20-22	20-34	20-46	20-58
33	17-20	17-32	17-45	17-57	18-09	18-21	18-33	18-45	18-57	19-09	19-21	19-33	19-45	19-57	20-09	20-21	20-33	20-45	20-57	21-09
34	17-31	17-43	17-56	18-08	18-20	18-32	18-44	18-56	19-08	19-20	19-32	19-44	19-56	20-08	20-20	20-32	20-44	20-56	21-08	21-20
35	17-42	17-54	18-07	18-19	18-31	18-43	18-55	19-07	19-19	19-31	19-43	19-55	20-07	20-19	20-31	20-43	20-55	21-07	21-19	21-31
36	17-53	18-05	18-18	18-30	18-42	18-54	19-06	19-18	19-30	19-42	19-54	20-06	20-18	20-30	20-42	20-54	21-06	21-18	21-30	21-42
37	18-04	18-16	18-29	18-41	18-53	19-05	19-17	19-29	19-41	19-53	20-05	20-17	20-29	20-41	20-53	21-05	21-17	21-29	21-41	21-53
38	18-15	18-27	18-40	18-52	19-04	19-16	19-28	19-40	19-52	20-04	20-16	20-28	20-40	20-52	21-04	21-16	21-28	21-40	21-52	22-04
39	18-26	18-38	18-51	19-03	19-15	19-27	19-39	19-51	20-03	20-15	20-27	20-39	20-51	21-03	21-15	21-27	21-39	21-51	22-03	22-15
40	18-37	18-49	19-02	19-14	19-26	19-38	19-50	20-02	20-14	20-26	20-38	20-50	21-02	21-14	21-26	21-38	21-50	22-02	22-14	22-26
41	18-48	19-00	19-13	19-25	19-37	19-49	20-01	20-13	20-25	20-37	20-49	21-01	21-13	21-25	21-37	21-49	22-01	22-13	22-25	22-37
42	18-59	19-11	19-24	19-36	19-48	20-00	20-12	20-24	20-36	20-48	21-00	21-12	21-24	21-36	21-48	22-00	22-12	22-24	22-36	22-48
43	19-10	19-22	19-35	19-47	19-59	20-11	20-23	20-35	20-47	20-59	21-11	21-23	21-35	21-47	21-59	22-11	22-23	22-35	22-47	22-59
44	19-21	19-33	19-46	19-58	20-10	20-22	20-34	20-46	20-58	21-10	21-22	21-34	21-46	21-58	22-10	22-22	22-34	22-46	22-58	23-10
45	19-32	19-44	19-57	20-09	20-21	20-33	20-45	20-57	21-09	21-21	21-33	21-45	21-57	22-09	22-21	22-33	22-45	22-57	23-09	23-21
46	19-43	19-55	20-08	20-20	20-32	20-44	20-56	21-08	21-20	21-32	21-44	21-56	22-08	22-20	22-32	22-44	22-56	23-08	23-20	23-32
47	19-54	20-06	20-19	20-31	20-43	20-55	21-07	21-19	21-31	21-43	21-55	22-07	22-19	22-31	22-43	22-55	23-07	23-19	23-31	23-43
48	20-05	20-17	20-30	20-42	20-54	21-06	21-18	21-30	21-42	21-54	22-06	22-18	22-30	22-42	22-54	23-06	23-18	23-30	23-42	23-54
49	20-16	20-28	20-41	20-53	21-05	21-17	21-29	21-41	21-53	22-05	22-17	22-29	22-41	22-53	23-05	23-17	23-29	23-41	23-53	24-05
50	20-27	20-39	20-52	21-04	21-16	21-28	21-40	21-52	22-04	22-16	22-28	22-40	22-52	23-04	23-16	23-28	23-40	23-52	24-04	24-16
51	20-38	20-50	21-03	21-15	21-27	21-39	21-51	22-03	22-15	22-27	22-39	22-51	23-03	23-15	23-27	23-39	23-51	24-03	24-15	24-27
52	20-49	21-01	21-14	21-26	21-38	21-50	22-02	22-14	22-26	22-38	22-50	23-02	23-14	23-26	23-38	23-50	24-02	24-14	24-26	24-38
53	20-60	21-12	21-25	21-37	21-49	22-01	22-13	22-25	22-37	22-49	23-01	23-13	23-25	23-37	23-49	24-01	24-13	24-25	24-37	24-49
54	20-71	21-23	21-36	21-48	22-00	22-12	22-24	22-36	22-48	23-00	23-12	23-24	23-36	23-48	24-00	24-12	24-24	24-36	24-48	25-00
55	20-82	21-34	21-47	21-59	22-11	22-23	22-35	22-47	22-59	23-11	23-23	23-35	23-47	23-59	24-11	24-23	24-35	24-47	24-59	25-11

TABLE H₂—15-CANDLE GAS.

TABLE giving the ILLUMINATING POWER OF GAS as calculated from Observations of the Rate of Consumption required to yield the Light of 15 Candles, and from Reading of the Barometer, Thermometer, and Refractive Tables, of the Aerothermometer. The observed time of passage through the meter of one-sixteenth of a cubic foot of gas is to be found in the left-hand column; and the Aerothermometer Reading or Tabular Number in the top lines. In the corresponding line and column is found the Illuminating Power.

Aerothermometer...	.8900	.9400	.9500	.9600	.9700	.9800	.9900	1.0000	1.0100	1.0200	1.0300	1.0400	1.0500	1.0600	1.0700	1.0800	1.0900	1.1000	1.1100	1.1200
Tabular Number.	1.0150	1.0644	1.0533	1.0425	1.0311	1.0200	1.0100	1.0000	.9900	.9800	.9700	.9600	.9500	.9400	.9300	.9200	.9100	.9000	.8900	.8800
Minute, Seconds,	12.09	12.22	12.35	12.47	12.60	12.73	12.86	12.99	13.12	13.25	13.38	13.51	13.65	13.78	13.91	14.04	14.17	14.30	14.43	14.56
1	44	12.31	12.44	12.57	12.70	12.83	12.96	13.09	13.22	13.35	13.48	13.61	13.74	13.87	14.00	14.13	14.26	14.39	14.52	14.65
2	45	12.32	12.45	12.58	12.71	12.84	12.97	13.10	13.23	13.36	13.49	13.62	13.75	13.88	14.01	14.14	14.27	14.40	14.53	14.66
3	46	12.33	12.46	12.59	12.72	12.85	12.98	13.11	13.24	13.37	13.50	13.63	13.76	13.89	14.02	14.15	14.28	14.41	14.54	14.67
4	47	12.34	12.47	12.60	12.73	12.86	12.99	13.12	13.25	13.38	13.51	13.64	13.77	13.90	14.03	14.16	14.29	14.42	14.55	14.68
5	48	12.35	12.48	12.61	12.74	12.87	13.00	13.13	13.26	13.39	13.52	13.65	13.78	13.91	14.04	14.17	14.30	14.43	14.56	14.69
6	49	12.36	12.49	12.62	12.75	12.88	13.01	13.14	13.27	13.40	13.53	13.66	13.79	13.92	14.05	14.18	14.31	14.44	14.57	14.70
7	50	12.37	12.50	12.63	12.76	12.89	13.02	13.15	13.28	13.41	13.54	13.67	13.80	13.93	14.06	14.19	14.32	14.45	14.58	14.71
8	51	12.38	12.51	12.64	12.77	12.90	13.03	13.16	13.29	13.42	13.55	13.68	13.81	13.94	14.07	14.20	14.33	14.46	14.59	14.72
9	52	12.39	12.52	12.65	12.78	12.91	13.04	13.17	13.30	13.43	13.56	13.69	13.82	13.95	14.08	14.21	14.34	14.47	14.60	14.73
10	53	12.40	12.53	12.66	12.79	12.92	13.05	13.18	13.31	13.44	13.57	13.70	13.83	13.96	14.09	14.22	14.35	14.48	14.61	14.74
11	54	12.41	12.54	12.67	12.80	12.93	13.06	13.19	13.32	13.45	13.58	13.71	13.84	13.97	14.10	14.23	14.36	14.49	14.62	14.75
12	55	12.42	12.55	12.68	12.81	12.94	13.07	13.20	13.33	13.46	13.59	13.72	13.85	13.98	14.11	14.24	14.37	14.50	14.63	14.76
13	56	12.43	12.56	12.69	12.82	12.95	13.08	13.21	13.34	13.47	13.60	13.73	13.86	13.99	14.12	14.25	14.38	14.51	14.64	14.77
14	57	12.44	12.57	12.70	12.83	12.96	13.09	13.22	13.35	13.48	13.61	13.74	13.87	14.00	14.13	14.26	14.39	14.52	14.65	14.78
15	58	12.45	12.58	12.71	12.84	12.97	13.10	13.23	13.36	13.49	13.62	13.75	13.88	14.01	14.14	14.27	14.40	14.53	14.66	14.79
16	59	12.46	12.59	12.72	12.85	12.98	13.11	13.24	13.37	13.50	13.63	13.76	13.89	14.02	14.15	14.28	14.41	14.54	14.67	14.80
17	00	12.47	12.60	12.73	12.86	12.99	13.12	13.25	13.38	13.51	13.64	13.77	13.90	14.03	14.16	14.29	14.42	14.55	14.68	14.81
18	01	12.48	12.61	12.74	12.87	13.00	13.13	13.26	13.39	13.52	13.65	13.78	13.91	14.04	14.17	14.30	14.43	14.56	14.69	14.82
19	02	12.49	12.62	12.75	12.88	13.01	13.14	13.27	13.40	13.53	13.66	13.79	13.92	14.05	14.18	14.31	14.44	14.57	14.70	14.83
20	03	12.50	12.63	12.76	12.89	13.02	13.15	13.28	13.41	13.54	13.67	13.80	13.93	14.06	14.19	14.32	14.45	14.58	14.71	14.84
21	04	12.51	12.64	12.77	12.90	13.03	13.16	13.29	13.42	13.55	13.68	13.81	13.94	14.07	14.20	14.33	14.46	14.59	14.72	14.85
22	05	12.52	12.65	12.78	12.91	13.04	13.17	13.30	13.43	13.56	13.69	13.82	13.95	14.08	14.21	14.34	14.47	14.60	14.73	14.86
23	06	12.53	12.66	12.79	12.92	13.05	13.18	13.31	13.44	13.57	13.70	13.83	13.96	14.09	14.22	14.35	14.48	14.61	14.74	14.87
24	07	12.54	12.67	12.80	12.93	13.06	13.19	13.32	13.45	13.58	13.71	13.84	13.97	14.10	14.23	14.36	14.49	14.62	14.75	14.88
25	08	12.55	12.68	12.81	12.94	13.07	13.20	13.33	13.46	13.59	13.72	13.85	13.98	14.11	14.24	14.37	14.50	14.63	14.76	14.89
26	09	12.56	12.69	12.82	12.95	13.08	13.21	13.34	13.47	13.60	13.73	13.86	13.99	14.12	14.25	14.38	14.51	14.64	14.77	14.90
27	10	12.57	12.70	12.83	12.96	13.09	13.22	13.35	13.48	13.61	13.74	13.87	14.00	14.13	14.26	14.39	14.52	14.65	14.78	14.91
28	11	12.58	12.71	12.84	12.97	13.10	13.23	13.36	13.49	13.62	13.75	13.88	14.01	14.14	14.27	14.40	14.53	14.66	14.79	14.92
29	12	12.59	12.72	12.85	12.98	13.11	13.24	13.37	13.50	13.63	13.76	13.89	14.02	14.15	14.28	14.41	14.54	14.67	14.80	14.93
30	13	12.60	12.73	12.86	12.99	13.12	13.25	13.38	13.51	13.64	13.77	13.90	14.03	14.16	14.29	14.42	14.55	14.68	14.81	14.94
31	14	12.61	12.74	12.87	13.00	13.13	13.26	13.39	13.52	13.65	13.78	13.91	14.04	14.17	14.30	14.43	14.56	14.69	14.82	14.95
32	15	12.62	12.75	12.88	13.01	13.14	13.27	13.40	13.53	13.66	13.79	13.92	14.05	14.18	14.31	14.44	14.57	14.70	14.83	14.96
33	16	12.63	12.76	12.89	13.02	13.15	13.28	13.41	13.54	13.67	13.80	13.93	14.06	14.19	14.32	14.45	14.58	14.71	14.84	14.97
34	17	12.64	12.77	12.90	13.03	13.16	13.29	13.42	13.55	13.68	13.81	13.94	14.07	14.20	14.33	14.46	14.59	14.72	14.85	14.98
35	18	12.65	12.78	12.91	13.04	13.17	13.30	13.43	13.56	13.69	13.82	13.95	14.08	14.21	14.34	14.47	14.60	14.73	14.86	14.99
36	19	12.66	12.79	12.92	13.05	13.18	13.31	13.44	13.57	13.70	13.83	13.96	14.09	14.22	14.35	14.48	14.61	14.74	14.87	15.00
37	20	12.67	12.80	12.93	13.06	13.19	13.32	13.45	13.58	13.71	13.84	13.97	14.10	14.23	14.36	14.49	14.62	14.75	14.88	15.01
38	21	12.68	12.81	12.94	13.07	13.20	13.33	13.46	13.59	13.72	13.85	13.98	14.11	14.24	14.37	14.50	14.63	14.76	14.89	15.02
39	22	12.69	12.82	12.95	13.08	13.21	13.34	13.47	13.60	13.73	13.86	13.99	14.12	14.25	14.38	14.51	14.64	14.77	14.90	15.03
40	23	12.70	12.83	12.96	13.09	13.22	13.35	13.48	13.61	13.74	13.87	14.00	14.13	14.26	14.39	14.52	14.65	14.78	14.91	15.04
41	24	12.71	12.84	12.97	13.10	13.23	13.36	13.49	13.62	13.75	13.88	14.01	14.14	14.27	14.40	14.53	14.66	14.79	14.92	15.05
42	25	12.72	12.85	12.98	13.11	13.24	13.37	13.50	13.63	13.76	13.89	14.02	14.15	14.28	14.41	14.54	14.67	14.80	14.93	15.06
43	26	12.73	12.86	12.99	13.12	13.25	13.38	13.51	13.64	13.77	13.90	14.03	14.16	14.29	14.42	14.55	14.68	14.81	14.94	15.07
44	27	12.74	12.87	13.00	13.13	13.26	13.39	13.52	13.65	13.78	13.91	14.04	14.17	14.30	14.43	14.56	14.69	14.82	14.95	15.08
45	28	12.75	12.88	13.01	13.14	13.27	13.40	13.53	13.66	13.79	13.92	14.05	14.18	14.31	14.44	14.57	14.70	14.83	14.96	15.09
46	29	12.76	12.89	13.02	13.15	13.28	13.41	13.54	13.67	13.80	13.93	14.06	14.19	14.32	14.45	14.58	14.71	14.84	14.97	15.10
47	30	12.77	12.90	13.03	13.16	13.29	13.42	13.55	13.68	13.81	13.94	14.07	14.20	14.33	14.46	14.59	14.72	14.85	14.98	15.11
48	31	12.78	12.91	13.04	13.17	13.30	13.43	13.56	13.69	13.82	13.95	14.08	14.21	14.34	14.47	14.60	14.73	14.86	14.99	15.12
49	32	12.79	12.92	13.05	13.18	13.31	13.44	13.57	13.70	13.83	13.96	14.09	14.22	14.35	14.48	14.61	14.74	14.87	15.00	15.13
50	33	12.80	12.93	13.06	13.19	13.32	13.45	13.58	13.71	13.84	13.97	14.10	14.23	14.36	14.49	14.62	14.75	14.88	15.01	15.14
51	34	12.81	12.94	13.07	13.20	13.33	13.46	13.59	13.72	13.85	13.98	14.11	14.24	14.37	14.50	14.63	14.76	14.89	15.02	15.15
52	35	12.82	12.95	13.08	13.21	13.34	13.47	13.60	13.73	13.86	13.99	14.12	14.25	14.38	14.51	14.64	14.77	14.90	15.03	15.16
53	36	12.83	12.96	13.09	13.22	13.35	13.48	13.61	13.74	13.87	14.00	14.13	14.26	14.39	14.52	14.65	14.78	14.91	15.04	15.17
54	37	12.84	12.97	13.10	13.23	13.36	13.49	13.62	13.75	13.88	14.01	14.14	14.27	14.40	14.53	14.66	14.79	14.92	15.05	15.18
55	38	12.85	12.98	13.11	13.24	13.37	13.50	13.63	13.76	13.89	14.02</									

TABLE H₃.—17-CANDLE GAS.

TABLE showing the ILLUMINATING POWER OF GAS as calculated from Observations of the Rate of Consumption required to yield the Light of 17 Candles, and from Readings of the Barometer, Thermometer, and Refractive Tables, or of the Aerothermometer. The observed time of passage through the meter of one-sixth of a cubic foot of gas is to be found in the left-hand column; and the Aerothermometer Reading or Tabular Number in the top lines. In the corresponding line and column is found the Illuminating Power.

Aerothermometer... Nabular Number.	1-075	1-080	1-085	1-090	1-095	1-100	1-105	1-110	1-115	1-120
Minute, Seconds.	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
1	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
2	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
3	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
4	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
5	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
6	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
7	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
8	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
9	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
10	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
11	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"
12	13' 50"	14' 00"	14' 10"	14' 20"	14' 30"	14' 40"	14' 50"	15' 00"	15' 10"	15' 20"

Illuminating Power = Aerothermometer Reading $\times$ Time in Seconds $\div$ 30388 or = Time in Seconds $\times$ Tabular Number

TABLE H₄.—18 CANDLE GAS.

TABLE giving the ILLUMINATING POWER OF GAS as calculated from Observations of the Rate of Consumption required to yield the Light of 18 Candles, and from Readings of the Barometer, Thermometer, and Refractive Tables, or of the Aerothermometer. The observed time of passage through the meter of one-sixth of a cubic foot of gas is to be found in the left-hand column; and the Aerothermometer Reading or Tabular Number in the top lines. In the corresponding line and column is found the Illuminating Power.

Aerothermometer... Tabular Number...	.930 .940 .950 .960 .970 .980 .990 1.000 1.010 1.020 1.030 1.040 1.050 1.060 1.070 .935 .926 .918 .909 .901 .893																			
	1.075 1.064 1.055 1.042 1.031 1.020 1.010 1.000	1.990 .980 .970 .960 .950 .940 .930 .920 .915 .909 .901 .893																		
Minutes, Seconds																				
1	14.51	14.66	14.82	14.98	15.13	15.29	15.44	15.60	15.76	15.91	16.07	16.22	16.38	16.54	16.69	16.85	17.00	17.16	17.32	17.47
2	14.65	14.80	14.96	15.12	15.28	15.43	15.59	15.75	15.91	16.06	16.22	16.38	16.54	16.69	16.85	17.01	17.17	17.33	17.48	17.64
3	14.79	14.95	15.10	15.26	15.42	15.58	15.74	15.90	16.06	16.22	16.38	16.54	16.69	16.85	17.01	17.17	17.33	17.49	17.65	17.81
4	14.93	15.09	15.25	15.41	15.57	15.73	15.89	16.04	16.20	16.36	16.52	16.69	16.85	17.01	17.17	17.33	17.49	17.65	17.81	17.98
5	15.07	15.23	15.39	15.55	15.71	15.88	16.04	16.20	16.36	16.51	16.68	16.84	17.00	17.17	17.33	17.50	17.66	17.82	17.98	18.14
6	15.20	15.37	15.53	15.70	15.86	16.02	16.19	16.35	16.51	16.68	16.84	17.00	17.17	17.33	17.49	17.66	17.82	17.98	18.15	18.31
7	15.34	15.51	15.67	15.84	16.00	16.17	16.33	16.50	16.66	16.83	16.99	17.16	17.32	17.49	17.65	17.82	17.98	18.15	18.31	18.48
8	15.48	15.65	15.82	15.98	16.15	16.32	16.48	16.65	16.82	16.98	17.15	17.32	17.48	17.65	17.81	17.98	18.15	18.31	18.48	18.65
9	15.62	15.79	15.96	16.13	16.30	16.46	16.63	16.80	16.97	17.13	17.31	17.47	17.64	17.81	17.98	18.14	18.31	18.48	18.65	18.82
10	15.76	15.93	16.10	16.27	16.44	16.61	16.78	16.95	17.12	17.29	17.47	17.63	17.80	17.97	18.14	18.31	18.47	18.64	18.81	18.98
11	15.90	16.07	16.24	16.41	16.59	16.76	16.93	17.10	17.27	17.44	17.62	17.78	17.95	18.13	18.30	18.47	18.64	18.81	18.98	19.15
12	16.04	16.21	16.39	16.56	16.73	16.90	17.08	17.25	17.42	17.59	17.78	17.94	18.11	18.28	18.46	18.63	18.80	18.97	19.15	19.32
13	16.18	16.36	16.53	16.70	16.88	17.05	17.23	17.40	17.57	17.75	17.93	18.10	18.27	18.44	18.62	18.79	18.97	19.14	19.31	19.48
14	16.32	16.50	16.67	16.85	17.02	17.20	17.37	17.55	17.72	17.90	18.08	18.25	18.43	18.60	18.78	18.95	19.13	19.30	19.48	19.66
15	16.46	16.64	16.81	16.99	17.17	17.35	17.52	17.70	17.88	18.05	18.24	18.41	18.58	18.76	18.94	19.12	19.30	19.47	19.65	19.82
16	16.60	16.78	16.96	17.14	17.31	17.49	17.67	17.85	18.03	18.21	18.39	18.56	18.74	18.92	19.10	19.28	19.46	19.63	19.81	19.99
17	16.74	16.92	17.10	17.28	17.46	17.64	17.82	18.00	18.18	18.36	18.55	18.72	18.90	19.08	19.26	19.44	19.62	19.80	19.98	20.16
18	16.88	17.06	17.24	17.42	17.60	17.79	17.97	18.15	18.33	18.51	18.70	18.88	19.06	19.24	19.42	19.60	19.78	19.96	20.15	20.33
19	17.02	17.20	17.38	17.56	17.75	17.93	18.12	18.30	18.48	18.67	18.86	19.04	19.23	19.41	19.59	19.77	19.95	20.13	20.31	20.50
20	17.16	17.34	17.53	17.71	17.90	18.08	18.26	18.45	18.63	18.82	19.01	19.19	19.37	19.56	19.74	19.93	20.11	20.29	20.48	20.66
21	17.30	17.48	17.67	17.86	18.04	18.23	18.41	18.60	18.79	18.97	19.17	19.34	19.53	19.72	19.90	20.08	20.27	20.46	20.65	20.83
22	17.44	17.62	17.81	18.00	18.18	18.37	18.56	18.75	18.94	19.12	19.32	19.50	19.69	19.87	20.06	20.25	20.44	20.62	20.81	21.00
23	17.58	17.77	17.95	18.14	18.33	18.52	18.71	18.90	19.09	19.28	19.48	19.66	19.84	20.03	20.22	20.41	20.60	20.79	20.98	21.17
24	17.72	17.91	18.10	18.29	18.48	18.67	18.86	19.05	19.24	19.43	19.62	19.81	20.00	20.19	20.38	20.57	20.76	20.95	21.14	21.34
25	17.86	18.05	18.24	18.43	18.62	18.81	19.01	19.20	19.39	19.58	19.78	19.97	20.16	20.35	20.54	20.74	20.93	21.12	21.31	21.50
26	17.99	18.18	18.38	18.58	18.77	18.96	19.16	19.35	19.54	19.74	19.93	20.12	20.32	20.51	20.70	20.90	21.09	21.28	21.48	21.67
27	18.13	18.33	18.52	18.72	18.91	19.11	19.30	19.50	19.69	19.89	20.08	20.28	20.47	20.67	20.86	21.06	21.25	21.45	21.64	21.84
28	18.27	18.47	18.67	18.86	19.06	19.26	19.45	19.65	19.85	20.04	20.24	20.44	20.63	20.83	21.02	21.22	21.42	21.61	21.81	22.01
29	18.41	18.61	18.81	19.01	19.21	19.40	19.60	19.80	20.00	20.20	20.39	20.59	20.79	20.98	21.18	21.38	21.58	21.78	21.98	22.18

Illuminating Power = Aerothermometer Reading $\times$ Time in Seconds, or = $\frac{6.6}{\text{Tabular Number}}$ Time in Seconds

TABLE H₂.—10-CANDLE GAS.

TABLE giving the ILLUMINATING POWER OF GAS as calculated from Observations of the Rate of Consumption required to yield the Light of 10 Candles, and from Readings of the Barometer, Thermometer, and Refractive Tables, or of the Aerothermometer. The observed time of passage through the meter of one-sixth of a cubic foot of gas is to be found in the left-hand column; and the Aerothermometer Reading or Tabular Number in the top lines. In the corresponding line and column is found the Illuminating Power.

Aerothermometer, Tabular Number.	.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660		.650		.640		.630		.620		.610		.600		.590		.580		.570		.560		.550		.540		.530		.520		.510		.500		.490		.480		.470		.460		.450		.440		.430		.420		.410		.400		.390		.380		.370		.360		.350		.340		.330		.320		.310		.300		.290		.280		.270		.260		.250		.240		.230		.220		.210		.200		.190		.180		.170		.160		.150		.140		.130		.120		.110		.100		.090		.080		.070		.060		.050		.040		.030		.020		.010		.000		.990		.980		.970		.960		.950		.940		.930		.920		.910		.900		.890		.880		.870		.860		.850		.840		.830		.820		.810		.800		.790		.780		.770		.760		.750		.740		.730		.720		.710		.700		.690		.680		.670		.660			
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TABLE H₆—20-CANDLE GAS.

TABLE giving the ILLUMINATING POWER OF GAS as calculated from Observations of the Rate of Consumption required to yield the Light of 20 Candles, and from Readings of the Barometer, Thermometer, and Refractive Tables, or of the Aerothermometer. The observed time of passage through the meter of one-sixth of a cubic foot of gas is to be found in the left-hand column; and the Aerothermometer Reading or Tabular Number in the top lines. In the corresponding line and column is found the Illuminating Power.

Aerothermometer... Tabular Number.	.930	.940	.950	.960	.970	.980	.990	1.000	1.010	1.020	1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100	1.110	1.120
Minutes, Seconds.	1.075	1.064	1.053	1.043	1.031	1.020	1.010	1.000	.990	.980	.970	.962	.953	.944	.935	.926	.918	.909	.901	.893
1	16.12	16.30	16.47	16.64	16.81	16.99	17.16	17.33	17.51	17.68	17.85	18.03	18.21	18.37	18.55	18.72	18.89	19.07	19.24	19.41
2	16.27	16.45	16.62	16.80	16.97	17.15	17.32	17.50	17.67	17.85	18.02	18.20	18.37	18.55	18.72	18.90	19.07	19.25	19.42	19.60
3	16.43	16.61	16.78	16.96	17.14	17.31	17.49	17.67	17.84	18.01	18.19	18.37	18.55	18.73	18.90	19.08	19.25	19.43	19.61	19.79
4	16.58	16.76	16.94	17.12	17.30	17.48	17.65	17.83	18.01	18.19	18.37	18.55	18.72	18.90	19.08	19.26	19.44	19.62	19.80	20.00
5	16.74	16.92	17.10	17.28	17.46	17.64	17.82	18.00	18.18	18.36	18.54	18.72	18.90	19.08	19.26	19.44	19.62	19.80	20.00	20.16
6	16.89	17.07	17.25	17.43	17.61	17.79	17.97	18.15	18.33	18.51	18.69	18.87	19.05	19.23	19.41	19.59	19.77	19.95	20.13	20.35
7	17.05	17.23	17.41	17.59	17.77	17.95	18.13	18.31	18.49	18.67	18.85	19.03	19.21	19.39	19.57	19.75	19.93	20.11	20.33	20.53
8	17.20	17.38	17.56	17.74	17.92	18.10	18.28	18.46	18.64	18.82	19.00	19.18	19.36	19.54	19.72	19.90	20.08	20.26	20.52	20.72
9	17.36	17.54	17.72	17.90	18.08	18.26	18.44	18.62	18.80	18.98	19.16	19.34	19.52	19.70	19.88	20.06	20.24	20.50	20.72	20.91
10	17.51	17.69	17.87	18.05	18.23	18.41	18.59	18.77	18.95	19.13	19.31	19.49	19.67	19.85	20.03	20.21	20.39	20.65	20.90	21.09
11	17.67	17.85	18.03	18.21	18.39	18.57	18.75	18.93	19.11	19.29	19.47	19.65	19.83	20.01	20.19	20.37	20.55	20.81	21.06	21.28
12	17.83	18.01	18.19	18.37	18.55	18.73	18.91	19.09	19.27	19.45	19.63	19.81	19.99	20.17	20.35	20.53	20.71	20.97	21.27	21.47
13	17.98	18.17	18.35	18.53	18.71	18.89	19.07	19.25	19.43	19.61	19.79	19.97	20.15	20.33	20.51	20.69	20.87	21.13	21.46	21.65
14	18.13	18.33	18.52	18.71	18.89	19.08	19.26	19.44	19.62	19.80	19.98	20.16	20.34	20.52	20.70	20.88	21.06	21.32	21.64	21.84
15	18.29	18.49	18.68	18.87	19.06	19.24	19.43	19.61	19.79	19.97	20.15	20.33	20.51	20.69	20.87	21.05	21.23	21.49	21.81	22.03
16	18.44	18.64	18.84	19.04	19.24	19.44	19.64	19.84	20.04	20.24	20.43	20.63	20.82	21.02	21.21	21.41	21.61	21.81	22.11	22.31
17	18.60	18.80	19.00	19.20	19.40	19.60	19.80	20.00	20.20	20.40	20.60	20.80	21.00	21.20	21.40	21.60	21.80	22.00	22.30	22.50
18	18.75	18.96	19.16	19.36	19.56	19.76	19.96	20.17	20.37	20.57	20.77	20.97	21.17	21.38	21.58	21.78	21.98	22.18	22.38	22.59
19	18.91	19.11	19.32	19.52	19.72	19.92	20.13	20.33	20.53	20.74	20.94	21.14	21.35	21.55	21.76	21.96	22.16	22.36	22.57	22.77
20	19.06	19.27	19.47	19.68	19.88	20.09	20.30	20.50	20.70	20.91	21.11	21.32	21.52	21.73	21.93	22.14	22.34	22.55	22.75	22.96
21	19.22	19.43	19.63	19.84	20.05	20.25	20.47	20.67	20.87	21.08	21.29	21.49	21.70	21.91	22.11	22.32	22.52	22.73	22.94	23.15
22	19.37	19.59	19.79	20.00	20.21	20.41	20.63	20.83	21.04	21.25	21.46	21.66	21.87	22.08	22.29	22.50	22.70	22.91	23.12	23.33
23	19.53	19.74	19.95	20.16	20.37	20.58	20.79	20.99	21.21	21.42	21.63	21.84	22.05	22.26	22.47	22.68	22.89	23.10	23.31	23.53
24	19.68	19.90	20.11	20.32	20.53	20.74	20.95	21.16	21.38	21.59	21.80	22.01	22.22	22.43	22.65	22.86	23.07	23.28	23.49	23.71
25	19.84	20.06	20.26	20.48	20.69	20.90	21.11	21.33	21.54	21.76	21.97	22.18	22.39	22.60	22.82	23.04	23.25	23.46	23.68	23.89
26	20.00	20.21	20.42	20.64	20.85	21.06	21.28	21.49	21.71	21.93	22.14	22.36	22.57	22.79	23.00	23.22	23.43	23.65	23.86	24.08
27	20.15	20.37	20.58	20.80	21.02	21.24	21.46	21.67	21.89	22.11	22.32	22.53	22.75	22.97	23.18	23.40	23.62	23.83	24.05	24.27
28	20.30	20.53	20.74	20.96	21.18	21.40	21.62	21.83	22.05	22.27	22.49	22.70	22.92	23.14	23.36	23.58	23.79	24.01	24.23	24.45
29	20.46	20.68	20.90	21.12	21.34	21.56	21.78	22.00	22.22	22.44	22.66	22.88	23.10	23.32	23.54	23.76	23.98	24.20	24.42	24.64

Illuminating Power = $\frac{\text{Aerothermometer Reading} \times \text{Time in Seconds}}{60}$ or = $\frac{\text{Time in Seconds}}{60} \times \text{Tabular Number}$.

TABLE J.

AN ARRANGEMENT GIVING THE SUBSTANCE OF THE NOTIFICATION OF THE GAS REFEREES, PREVIOUS TO THE ADOPTION IN LONDON OF THE T. BLE PHOTOMETER.

As to the Candles to be Used for Testing Illuminating Power.

The candles to be used for testing the illuminating power of gas are defined by the Metropolitan Gas Acts as "sperm candles of six to the pound, each burning 120 grains an hour." Before being issued to the Gas Examiners the candles shall be sent to the Office of the Gas Referees, by whom samples from each batch will be examined and tested.

Packets of candles approved by the Gas Referees will be sealed by them and certified for use in the testing places. No other candles than those which have thus been sealed and certified shall be used for gas testing.

In order to diminish as far as possible the differences found to exist between different candles, it is desirable that the following regulations (including a previous examination of wicks by the Referees) should be adhered to, but for the present the Referees will examine any candles which may be submitted to them by the proper authorities, and will, if the candles on examination are found to be satisfactory, certify them for use in the testing places.

REGULATIONS FOR SECURING UNIFORMITY IN STANDARD CANDLES.

1. The wicks shall be made of three strands of cotton plaited together, each strand consisting of 18 threads. The strands shall be plaited with such closeness, that when the wick is laid upon a rule and extended by a pull of about 1 oz., just sufficient to straighten it, the number of plaits in 4 inches shall not exceed 34 nor fall short of 32.

Each wick shall be of suitable length, not less than 12 inches, and looped ready for fixing in the mould. After having been bleached in the usual manner and thoroughly washed the wicks shall be steeped in a liquid made by dissolving one ounce of sal ammoniac and half an ounce of crystallised boracic acid in a gallon of distilled water; they are then to be gently wrung or pressed till most of the liquid has been removed, and dried at a moderate heat while lying horizontally.

Such a wick cut to a length of 12 inches when stretched as above shall weigh not more than 7 nor less than 6 grains. The weight of the ash remaining after the burning of ten wicks which have not been steeped in boracic acid, or from which the boracic acid has been washed out, shall be not more than 0.03 grain.

Wicks made in accordance with this prescription shall be sent to the office of the Gas Referees, by whom they will be examined and certified.

The wicks so certified are to be used by the candle-maker in the condition in which they are returned to him.

When the wicks are set in the mould they should be pulled with only so much force as is necessary to straighten them.

2. The Spermaceti of which the candles are made shall be genuine Spermaceti, extracted in the United Kingdom from crude sperm oil, the product of the Sperm Whale (*Physeter Macrocephalus*). It shall be so refined as to have a melting point lying between 112° and 115° Fahr.

Since candles made with Spermaceti alone are brittle, and the cup which they form in burning has an uneven edge, it is necessary to add a small proportion of beeswax or paraffin to remedy these defects. The best air-bleached beeswax, melting at or about 144° Fahr., and no other material, shall be used for this purpose, and the proportion of beeswax to Spermaceti shall be not less than 3 per cent. nor more than 4½ per cent.

3. The candles made with the materials above prescribed shall each weigh, as nearly as may be, one-sixth of a pound, and will be found to answer to the following test. Immerse a candle taper-end downwards in water of 60° Fahr. with

a brass weight of 40 grains attached to the wick by a small piece of thread; when a further weight of 2 grains is laid on the butt end of the candle it will still float, but with a weight of 4 grains it will sink.

The candles shall be sent to the office of the Gas Referees, by whom samples from each batch will be examined and tested. Each batch of candles shall be accompanied by a specimen of the Spermaceti (unmixed with beeswax) which was used in making them.

4. METHOD OF WASHING WICKS.—As it is found to conduce to the regular burning of candles that the wicks should have been as far as possible cleaned and freed from mineral matters, it is recommended that the candle-maker, before steeping the wicks, shall wash them first in distilled water made alkaline with between 1 and 2 per cent. of strong liquid ammonia, then soak them for several hours in dilute nitric acid containing about 10 per cent. of strong acid, and finally wash them in distilled water made alkaline with a few drops of ammonia.

5. METHOD OF DETERMINING THE MELTING POINT OF THE SPERMACETI.—As various methods are used by different refiners of Spermaceti for determining the melting point, which lead to different results, it must be noted that the temperatures here given as the limits within which the melting point of a sample of refined Spermaceti should fall, viz., 112° to 115° Fahr., have been found by the following method, which is known as the capillary-tube method.

A small portion of the Spermaceti is placed in a short test-tube, and melted by plunging the lower end of the tube in hot water. A glass tube drawn out at one end into a capillary tube about 1 m.m. in diameter is dipped narrow end downwards into the liquid Spermaceti, so that, when the tube is withdrawn, 2 or 3 m.m. of its length are filled with Spermaceti, which immediately solidifies. The corresponding part of the exterior of the tube also becomes coated with Spermaceti which must be removed.

The narrow part of the tube is then immersed in a large

vessel of water at a temperature not exceeding 110° Fahr. The lower end of the tube which contains the Spermaceti should be 3 or 4 inches below the surface and close to the bulb of a thermometer. The upper end of the tube must be above the surface, and the interior of the tube must contain no water. The water is then slowly heated, being at the same time briskly stirred so that the temperature of the whole mass is as uniform as possible. When the plug of Spermaceti in the tube melts, it will be forced up the tube by the pressure of the water. The temperature at the moment when this movement is observed is the melting point.

As to the Times and Mode of Testing for Illuminating Power.

The testings for Illuminating Power shall be three in number daily. But if the average of three testings of illuminating power falls below the prescribed illuminating power, a fourth testing shall be made. It is required (Gaslight and Coke and other Gas Companies Acts Amendment Act of 1880, section 7) "that the tests for illuminating power shall be taken at intervals of not less than one hour." Also (section 8) "the average of all the testings at any testing place on each day of the illuminating power of the gas supplied by the Company, at such testing place, shall be deemed to represent the illuminating power of such gas on that day at such testing place."

The Photometers to be used in the testing places shall be the improved forms of the Bunsen Photometer, prescribed and certified by the Referees.

The burner attached to each Photometer shall be a standard burner corresponding to that which has been deposited with the Warden of the Standards in accordance with section 37 of the Gaslight and Coke Company's Act, 1876.

The gas in the Photometer is to be kept burning for at least fifteen minutes before any testing is made; and no gas shall pass through the meter attached to the Photometer except that which is consumed by the standard burner in testing or during the intervals between the testings made on any day.

The disc used in the Photometer shall be either the improved Leeson or the Bunsen disc. When a disc is not in use, it should be covered to protect it from dust; and if a disc is in any way marked or soiled, a clean disc is to be substituted.

A clean chimney is to be placed on the burner before each testing.

The candles shall be such as are prescribed above. Two of these candles, or two of the half-candles formed by cutting one of these candles in two, shall be used together. The three testings made on one day shall be made with three different pairs of candles or half-candles.

Each testing shall consist of ten observations of the Photometer, made at intervals of one minute. When five observations have been made, the disc and mirrors are to be reversed by being turned round through half a circle. The average of each set of ten observations is to be taken as representing the illuminating power for that testing.

The rate of burning of the gas in each burner shall be five cubic feet per hour—a rate of consumption which is shown by the long hand of the meter making exactly one revolution per minute for several minutes consecutively.

The candles are to be lighted at least fifteen minutes before the beginning of each testing, so as to have attained their normal rate of burning. The Gas Examiner may ascertain whether the candles are burning at nearly the normal rate by placing a four-grain weight in the candle-pan when the balance turns, and observing whether the balance turns again after the lapse of one minute. Before each testing the two candles are to be so placed that the plane of the curvature of one wick shall be perpendicular to the plane of the curvature of the other wick, and the candle-balance is to be so adjusted that the axes of both flames shall lie exactly between the two plumb-lines which mark the position of the zero of the scale.

Before and after making each testing the Gas Examiner shall counterpoise the candles; and if the rate of consumption per candle shall not have exceeded 126 grains per hour, or fallen short of 114 grains per hour, he shall make, and record

in a book to be kept for the purpose, the calculations requisite to neutralise the effects of the divergence from 120 grains per hour. If the rate of consumption shall have varied from the prescribed rate beyond the above-named limits; or if the Gas Examiner should observe, during the testing, that the candles are burning irregularly, or that their flames are not exactly between the two plumb-lines, the testing is to be rejected and a fresh testing made.

Instead of weighing the candles the Gas Examiner may observe the time in which 40 grains are burnt. This must not exceed 10.5 or fall short of 9.5 minutes.

The Gas Examiner shall, at least once a week, compare the Meter Clock with the standard clock in each testing place.

At the time of each testing the Gas Examiner shall observe and record the temperature of the gas, as shown by the thermometer attached to the meter, and also the height of the Barometer. The volumes of the gas operated upon during the testings may be corrected from these data (the standard of comparison being, for the Barometer, 30 inches; and for the Thermometer, 60 degrees) by means of the Table. Suppose, for example, the Thermometer stands at 54 degrees, and the Barometer at 30.3 inches: multiply the quantity of gas consumed by the corresponding *Tabular number*—the product will be the corrected volume of the gas, *i. e.*, the volume the gas would have occupied when measured over water at the standard temperature and pressure. Thus:

Volume of Gas consumed.....	5 cubic feet.
Tabular number for Bar-	
ometer and Thermometer	1.025
Then $1.025 \times 5 = 5.125$ the corrected volume.	

Instead of thus correcting the volume of gas consumed, the same object may be attained by dividing the observed illuminating power by the Tabular number, or by multiplying the observed illuminating power by the reading of the Aeror-
thometer.

The Gas Examiner shall enter in his book the particulars of every testing of illuminating power made by him at the testing places, during or immediately after such testing; and in the case of any testing which he rejects he shall also state the cause of rejection. No testing is to be rejected on the ground that the result seems improbable.

The calculations for working out the corrections, etc., for the illuminating power of the gas proceed in the following manner. Add the observations together and divide the sum by 10 to get the average; then, as two candles are used, multiply by 2, to get the illuminating power of the gas if tried against one candle. Then, as the standard rate of consumption of the candles (viz., 120 grains) is to the average number of grains consumed by each per hour, so is the above-obtained number to the actual Illuminating Power. Finally, make the correction for Temperature and Pressure, by dividing the illuminating power by the Tabular number. For example (taking the Tabular number as 1.025):

Observations:

1st minute	—7.8	Consumption of the 2
2d	" 7.8	candles in 10 minutes.
3d	" 8.1	= 41 grains.
4th	" 8.2	3
5th	" 8.3	—
6th	" 8.5	123 = Consumption
7th	" 8.6	of 1 candle per hour.
8th	" 8.4	
9th	" 8.3	
10th	" 8.6	

10) 82.6

Average, by 2 candles, = 8.26

2

Average, by 1 candle, = 16.52

Consumption by 1
candle per hour... 123 grains

4956
3304
1652

Standard con-
sumption... 120) 203196

Correction for
temp. & pres. 1025) 16933(16.5

1025

6683
6150

5330

= corrected
Illum. Power
in candles.

The foregoing calculation can be shortened as follows:

Observations:

1st minute—	7.8
2d “	7.8
3d “	8.1
4th “	8.2
5th “	8.3
6th “	8.5
7th “	8.6
8th “	8.4
9th “	8.3
10th “	8.6
	81.6

Consumption by two
candles in 10 minutes

41 grains.

826

3304

2) 33866

Tabular number.. 1025) 16933 (16.5

1025

6683

6150

5330

= corrected
Illum. Power
in candles.

As to the Mode of Testing the Pressure at Which Gas is Supplied.

Testings of pressure shall be made by unscrewing the Governor and Burner of one of the ordinary public lamps, in such street or part of a street as the Controlling Authority may from time to time appoint, and attaching in their stead a portable pressure gauge.

Each testing place is provided with a gauge prescribed for

this purpose by the Referees, consisting of an ordinary pressure gauge inclosed in a lantern, which also holds a candle for throwing light upon the tubes and scale. The difference of level of the water in the two limbs of the gauge is read by means of a sliding scale, the zero of which is made to coincide with the top of the lower column of liquid.

The Gas Examiner having fixed the gauge gas-tight, and as nearly as possible vertical on the pipe of the lamp, and having opened the cocks of the lamp and gauge, shall read and at once record the pressure shown. From the observed pressure one-tenth of an inch is to be deducted to correct for the difference between the pressure of gas at the top of the lamp column and that at which it is supplied to the basement of the neighbouring houses.

A drawing and description of the Street Lamp Pressure Gauge follows:

This instrument has been designed by us, in compliance with Sect. 6 of the Gas Light and Coke and other Gas Companies Acts Amendment Act, 1880, for the purpose of testing in any street at any hour the pressure at which gas is supplied. Its construction and mode of use are as follows:

Within a lantern provided with a handle for carrying and feet for resting on the ground, is placed a candle-lamp, to give light for reading the gauge. In front of the candle-lamp is a sheet of opal glass, and in front of this a glass U-tube, partly filled with coloured water, and communicating at one end with the air, at the other with a metal pipe, which passes through the bottom of the lantern. In order to read easily and accurately the difference of level of the liquid in the two limbs, a scale divided into tenths of an inch is made to slide between them with sufficient friction to retain it in any position. The zero of the scale having been brought level with the surface of the liquid which is pressed upon by the gas, the height above this of the surface which is pressed upon by the air can be read directly. The lantern is closed in front by a glass door, at each side of which is a reflector for throwing light upon the scale of the gauge. Above each limb of the U-tube is a tap which

can be closed when the instrument is not in use, to prevent the liquid being accidentally spilt.

To make a testing of pressure the governor and burner of a street lamp are to be removed, and the pressure gauge is to be screwed on to the gas-pipe, by which it is supported. The cock is then turned on, and a reading made. If on turning off the cock the level of the liquid is unchanged, or changes slowly, the reading is correct; but if the level changes quickly, the junction between the lamp and the gauge must be made more perfect, and the testing repeated. A small leakage is immaterial, provided the cock is turned fully on.

The pressure at the top of a lamp column is greater by about 0.1 inch than that at the main, which is the pressure required. Accordingly a deduction of 0.1 inch from the observed pressure is to be made.

METERS.

The meters used for measuring the gas consumed in making the various testings, having been certified by the Referees, shall, at least once in seven days, be proved by the Gas Examiners by means of the Referees' Cubic-Foot Measure—a description of which apparatus, with directions how to use it, follows. Should a meter show any variation, water must be added or withdrawn until the meter is correct. Every testing place shall have the above-mentioned apparatus, so that the Gas Examiner may employ it whenever he thinks necessary.

No meter other than a wet one shall be used in testing the gas under these instructions.

THE GAS REFEREES' CUBIC-FOOT MEASURE.

DESCRIPTION OF THE CUBIC-FOOT MEASURE; THE METHOD OF
FIXING IT; AND DIRECTIONS FOR VERIFYING THE AC-
CURACY OF THE METERS CONNECTED WITH THE
PHOTOMETER AND WITH THE SULPHUR AND
AMMONIA TESTS.

THIS instrument is a vessel of a cylindrical form with rounded ends, made of hardened tin about one quarter of an inch thick, fitted at each end with a glass tube—the joints being made sound with India-rubber packing. The instrument stands in a vertical position firmly fixed to a strong plank.

At the top of the instrument is a three-way cock, marked on the head of the key with a T, each arm of which shows the direction of a way through the plug; and attached to the side of this cock there is a small pipe, which serves to admit gas when the Measure is to be charged. When the T is in its ordinary position, communication is closed between the Measure and the tube leading from it to the Meters, but is open to the gas supply; with the  in this position (*i. e.*, with the stem pointing to the *opposite* side of the cock to that connected with the gas supply) the Measure is open to the Meters and shut to the gas.

At the bottom of the instrument there are three cocks, one large and two small ones. One of the small ones, when opened, admits water into the Measure; the other small one is used for verifying the adjustment of the Measure, by discharging the water into a standard measure. The large cock, when opened, allows the water to run off.

The cock at the top of the Measure is continued by a tin pipe which rises above the level of the water in the cistern, and then returns downwards, passing to the two Meters.

Affixed round the glass tubes fitted to the upper and lower part of the Measure there are narrow strips of paper, which indicate the exact measure of One Cubic-Foot.

The instrument should be in communication with a tank of water in the same room.

To verify the Meters employed in ascertaining the consumption of Gas in the Photometers, or those employed in the Sulphur and Ammonia Tests, the mode of procedure is as follows:

Starting with the bottle filled with gas to below the water line, turn the upper three-way cock so as to close the inlet for gas, while opening the way to the Meters.

Next turn the cock of the Meter which is to be tested, so as to cut off the ordinary gas supply and to place the Meter in communication with the Cubic-Foot Measure, taking care that no other Meter is also open to the Cubic-Foot Measure. See that the tap is open which allows gas to pass from the Meter through the Governor to the Burner.

Then proceed gently to open the small lever-cock, and allow water to flow into the Measure sufficient to fill the lower glass tube up to the water line. Note the exact position of the index hands.

Now turn on the lever-cock, watching the pressure-gauge attached to the Measure, until gas is passing through the Meter at about the normal rate of five cubic feet an hour. When the Measure is nearly full, stand by to check the rate of flow, and finally shut the water off as it reaches the upper water line. Read the Meter.

Should the Meter have completed more than the prescribed number of revolutions when the Measure is full, then some water must be removed from the Meter; if the contrary is the case, then water must be added to that in the Meter. The Testing is then to be repeated until the Meter is found to register correctly.

The dial of the Photometer-meter is divided into 50 divisions; and as each revolution indicates one-twelfth of a foot, each division consequently represents the $\frac{1}{600}$ part of a Cubic-Foot; and therefore 6 of those divisions represent one hundredth part of a cubic-foot.

The dial of the Sulphur-meter is divided into 100 parts; and

as each complete revolution indicates one foot, each division consequently represents 1 per cent. of the volume sent through.

If the Cubic-Foot Measure, shortly before being used, has been filled with water whose temperature differs by more than two or three degrees from that of the air in the room, a sufficient time must be allowed to elapse after the Measure has been filled with gas, for the Measure to have gained the temperature of the air. If the temperature of the gas in the Cubic-Foot Measure, as indicated by the thermometer in the outlet tube, differs from that of the gas passing through the Meter, as indicated by the Thermometer of the Meter, the volume registered by the Meter is to be corrected by being multiplied by the tabular number corresponding to the barometric pressure and the temperature of the Meter, and divided by the tabular number corresponding to the same pressure and the temperature of the Cubic-Foot Measure. But since such a correction is only approximate, the Measure and the Meters should be so placed that the temperature of the air which surrounds them is nearly the same.

TABLE K.—SIMMANCE AND ABADY'S PATENT ILLUMINATING
EFFECT PHOTOMETER.

Table giving multipliers or factors for different angles, which factor when multiplied by the square of the base line (for Table of Squares see mathematical tables) gives the square of the distance from light under test to the disc. For instructions see paragraphs 102 to 107.

Angle.	Factor.	Angle.	Factor.	Angle.	Factor.	Angle.	Factor.
30°	1'333	41°5'	1'782	53°	2'761	64°5'	5'395
30°5'	1'347	42°	1'811	53°5'	2'826	65°	5'599
31°	1'36	42°5'	1'84	54°	2'894	65°5'	5'815
31°5'	1'375	43°	1'87	54°5'	2'965	66°	6'044
32°	1'39	43°5'	1'901	55°	3'039	66°5'	6'289
32°5'	1'406	44°	1'933	55°5'	3'117	67°	6'55
33°	1'422	44°5'	1'966	56°	3'198	67°5'	6'828
33°5'	1'438	45°	2'0	56°5'	3'283	68°	7'126
34°	1'455	45°5'	2'035	57°	3'371	68°5'	7'445
34°5'	1'472	46°	2'072	57°5'	3'464	69°	7'786
35°	1'49	46°5'	2'111	58°	3'561	69°5'	8'153
35°5'	1'508	47°	2'15	58°5'	3'663	70°	8'548
36°	1'527	47°5'	2'19	59°	3'77	70°5'	8'974
36°5'	1'547	48°	2'233	59°5'	3'883	71°	9'434
37°	1'568	48°5'	2'277	60°	4'0	71°5'	9'932
37°5'	1'589	49°	2'323	60°5'	4'124	72°	10'472
38°	1'610	49°5'	2'37	61°	4'254	72°5'	11'059
38°5'	1'633	50°	2'42	61°5'	4'389	73°	11'698
39°	1'656	50°5'	2'47	62°	4'537	73°5'	12'397
39°5'	1'680	51°	2'525	62°5'	4'69	74°	13'164
40°	1'704	51°5'	2'581	63°	4'849	74°5'	14'002
40°5'	1'729	52°	2'638	63°5'	5'023	75°	14'928
41°	1'755	52°5'	2'698	64°	5'204		

TABLE L.—CALORIFIC TABLES.

(See Chapter 4.)

DIVISIONS OF ORDINARY EXPERIMENTAL METER.													
C. C. of Water.	6	10	12	15	20	24	C. C. of Water.	6	10	12	15	20	24
150	15'0	9'0	7'5	6'0	4'5	3'75	250	25'0	15'0	12'5	10'0	7'5	6'25
152	15'2	9'12	7'6	6'08	4'56	3'8	252	25'2	15'12	12'6	10'08	7'56	6'3
154	15'4	9'24	7'7	6'16	4'62	3'88	254	25'4	15'24	12'7	10'16	7'62	6'35
156	15'6	9'36	7'8	6'24	4'68	3'95	256	25'6	15'36	12'8	10'24	7'68	6'4
158	15'8	9'48	7'9	6'32	4'74	3'95	258	25'8	15'48	12'9	10'32	7'74	6'45
160	16'0	9'6	8'0	6'4	4'8	4'0	260	26'0	15'6	13'0	10'4	7'8	6'5
162	16'2	9'72	8'1	6'48	4'86	4'05	262	26'2	15'72	13'1	10'48	7'86	6'55
164	16'4	9'84	8'2	6'56	4'92	4'1	264	26'4	15'84	13'2	10'56	7'92	6'6
166	16'6	9'96	8'3	6'64	4'98	4'15	266	26'6	15'96	13'3	10'64	7'98	6'65
168	16'8	10'08	8'4	6'72	5'04	4'2	268	26'8	16'08	13'4	10'72	8'04	6'7
170	17'0	10'2	8'5	6'8	5'1	4'25	270	27'0	16'2	13'5	10'8	8'1	6'75
172	17'2	10'32	8'6	6'88	5'16	4'3	272	27'2	16'32	13'6	10'88	8'16	6'8
174	17'4	10'44	8'7	6'96	5'22	4'35	274	27'4	16'44	13'7	10'96	8'22	6'85
176	17'6	10'56	8'8	7'04	5'28	4'4	276	27'6	16'56	13'8	11'04	8'28	6'9
178	17'8	10'68	8'9	7'12	5'34	4'45	278	27'8	16'68	13'9	11'12	8'34	6'95
180	18'0	10'8	9'0	7'2	5'4	4'5	280	28'0	16'8	14'0	11'2	8'4	7'0
182	18'2	10'92	9'1	7'28	5'46	4'55	282	28'2	16'92	14'1	11'28	8'46	7'05
184	18'4	11'04	9'2	7'36	5'52	4'6	284	28'4	17'04	14'2	11'36	8'52	7'1
186	18'6	11'16	9'3	7'44	5'58	4'65	286	28'6	17'16	14'3	11'44	8'58	7'15
188	18'8	11'28	9'4	7'52	5'64	4'7	288	28'8	17'28	14'4	11'52	8'64	7'2
190	19'0	11'4	9'5	7'6	5'7	4'75	290	29'0	17'4	14'5	11'6	8'7	7'25
192	19'2	11'52	9'6	7'68	5'76	4'8	292	29'2	17'52	14'6	11'68	8'76	7'3
194	19'4	11'64	9'7	7'76	5'82	4'85	294	29'4	17'64	14'7	11'76	8'82	7'35
196	19'6	11'76	9'8	7'84	5'88	4'9	296	29'6	17'76	14'8	11'84	8'88	7'4
198	19'8	11'88	9'9	7'92	5'94	4'95	298	29'8	17'88	14'9	11'92	8'94	7'45
200	20'0	12'0	10'0	8'0	6'0	5'0	300	30'0	18'0	15'0	12'0	9'0	7'5
202	20'2	12'12	10'1	8'08	6'06	5'05	302	30'2	18'12	15'1	12'08	9'06	7'55
204	20'4	12'24	10'2	8'16	6'12	5'1	304	30'4	18'24	15'2	12'16	9'12	7'6
206	20'6	12'36	10'3	8'24	6'18	5'15	306	30'6	18'36	15'3	12'24	9'18	7'65
208	20'8	12'48	10'4	8'32	6'24	5'2	308	30'8	18'48	15'4	12'32	9'24	7'7
210	21'0	12'6	10'5	8'4	6'3	5'25	310	31'0	18'6	15'5	12'4	9'3	7'75
212	21'2	12'72	10'6	8'48	6'36	5'3	312	31'2	18'72	15'6	12'48	9'36	7'8
214	21'4	12'84	10'7	8'56	6'42	5'35	314	31'4	18'84	15'7	12'56	9'42	7'85
216	21'6	12'96	10'8	8'64	6'48	5'4	316	31'6	18'96	15'8	12'64	9'48	7'9
218	21'8	13'08	10'9	8'72	6'54	5'45	318	31'8	19'08	15'9	12'72	9'54	7'95
220	22'0	13'2	11'0	8'8	6'6	5'5	320	32'0	19'2	16'0	12'8	9'6	8'0
222	22'2	13'32	11'1	8'88	6'66	5'55	322	32'2	19'32	16'1	12'88	9'66	8'05
224	22'4	13'44	11'2	8'96	6'72	5'6	324	32'4	19'44	16'2	12'96	9'72	8'1
226	22'6	13'56	11'3	9'04	6'78	5'65	326	32'6	19'56	16'3	13'04	9'78	8'15
228	22'8	13'68	11'4	9'12	6'84	5'7	328	32'8	19'68	16'4	13'12	9'84	8'2
230	23'0	13'8	11'5	9'2	6'9	5'75	330	33'0	19'8	16'5	13'2	9'9	8'25
232	23'2	13'92	11'6	9'28	6'96	5'8	332	33'2	19'92	16'6	13'28	9'96	8'3
234	23'4	14'04	11'7	9'36	7'02	5'85	334	33'4	20'04	16'7	13'36	10'02	8'35
236	23'6	14'16	11'8	9'44	7'08	5'9	336	33'6	20'16	16'8	13'44	10'08	8'4
238	23'8	14'28	11'9	9'52	7'14	5'95	338	33'8	20'28	16'9	13'52	10'14	8'45
240	24'0	14'4	12'0	9'6	7'2	6'0	340	34'0	20'4	17'0	13'6	10'2	8'5
242	24'2	14'52	12'1	9'68	7'26	6'05	342	34'2	20'52	17'1	13'68	10'26	8'55
244	24'4	14'64	12'2	9'76	7'32	6'1	344	34'4	20'64	17'2	13'76	10'32	8'6
246	24'6	14'76	12'3	9'84	7'38	6'15	346	34'6	20'76	17'3	13'84	10'38	8'65
248	24'8	14'88	12'4	9'92	7'44	6'2	348	34'8	20'88	17'4	13'92	10'44	8'7

TABLE L.—CALORIFIC TABLES.—Continued.

(See Chapter 4.)

DIVISIONS OF ORDINARY EXPERIMENTAL METER.													
C. C. of Water.	6	10	12	15	20	24	C. C. of Water.	6	10	12	15	20	24
350	35'0	21'0	17'5	14'0	10'5	8'75	450	45'0	27'0	22'5	18'0	13'5	11'25
352	35'2	21'12	17'6	14'08	10'56	8'8	452	45'2	27'12	22'6	18'08	13'56	11'3
354	35'4	21'24	17'7	14'16	10'62	8'85	454	45'4	27'24	22'7	18'16	13'62	11'35
356	35'6	21'36	17'8	14'24	10'68	8'9	456	45'6	27'36	22'8	18'24	13'68	11'4
358	35'8	21'48	17'9	14'32	10'74	8'95	458	45'8	27'48	22'9	18'32	13'74	11'45
360	36'0	21'6	18'0	14'4	10'8	9'0	460	46'0	27'6	23'0	18'4	13'8	11'5
362	36'2	21'12	18'1	14'48	10'86	9'05	462	46'2	27'12	23'1	18'48	13'86	11'55
364	36'4	21'24	18'2	14'56	10'92	9'1	464	46'4	27'24	23'2	18'56	13'92	11'6
366	36'6	21'36	18'3	15'04	10'98	9'15	466	46'6	27'36	23'3	19'04	13'98	11'65
368	36'8	22'08	18'4	15'12	11'04	9'2	468	46'8	28'08	23'4	19'12	14'04	11'7
370	37'0	22'2	18'5	15'2	11'1	9'25	470	47'0	28'2	23'5	19'2	14'1	11'75
372	37'2	22'32	18'6	15'28	11'16	9'3	472	47'2	28'32	23'6	19'32	14'16	11'8
374	37'4	22'44	18'7	15'36	11'22	9'35	474	47'4	28'44	23'7	19'44	14'22	11'85
376	37'6	22'56	18'8	15'44	11'28	9'4	476	47'6	28'56	23'8	19'56	14'28	11'9
378	37'8	22'68	18'9	15'52	11'34	9'45	478	47'8	29'08	23'9	19'12	14'34	11'95
380	38'0	22'8	19'0	15'6	11'4	9'5	480	48'0	29'2	24'0	19'2	14'4	12'0
382	38'2	22'92	19'1	15'68	11'46	9'55	482	48'2	29'12	24'1	19'32	14'46	12'05
384	38'4	23'04	19'2	15'76	11'52	9'6	484	48'4	29'24	24'2	19'44	14'52	12'1
386	38'6	23'16	19'3	15'84	11'58	9'65	486	48'6	29'36	24'3	19'56	14'58	12'15
388	38'8	23'28	19'4	15'92	11'64	9'7	488	48'8	29'48	24'4	19'12	14'64	12'2
390	39'0	23'4	19'5	16'0	11'7	9'75	490	49'0	29'6	24'5	19'6	14'7	12'25
392	39'2	23'52	19'6	16'08	11'76	9'8	492	49'2	29'12	24'6	19'68	14'76	12'3
394	39'4	23'64	19'7	16'16	11'82	9'85	494	49'4	29'24	24'7	19'76	14'82	12'35
396	39'6	23'76	19'8	16'24	11'88	9'9	496	49'6	29'36	24'8	19'84	14'88	12'4
398	39'8	23'88	19'9	16'32	11'94	9'95	498	49'8	29'48	24'9	19'92	14'94	12'45
400	40'0	24'0	20'0	16'4	12'0	10'0	500	50'0	30'0	25'0	20'0	15'0	12'5
402	40'2	24'12	20'1	16'48	12'06	10'05	502	50'2	30'12	25'1	20'08	15'06	12'55
404	40'4	24'24	20'1	16'56	12'12	10'1	504	50'4	30'24	25'2	20'16	15'12	12'6
406	40'6	24'36	20'3	17'04	12'18	10'15	506	50'6	30'36	25'3	20'24	15'18	12'65
408	40'8	24'48	20'4	17'12	12'24	10'2	508	50'8	30'48	25'4	20'32	15'24	12'7
410	41'0	24'6	20'5	17'2	12'3	10'25	510	51'0	30'6	25'5	20'4	15'3	12'75
412	41'2	24'72	20'6	17'28	12'36	10'3	512	51'2	30'72	25'6	20'48	15'36	12'8
414	41'4	24'84	20'7	17'36	12'42	10'35	514	51'4	30'84	25'7	20'56	15'42	12'85
416	41'6	24'96	20'8	17'44	12'48	10'4	516	51'6	30'96	25'8	20'64	15'48	12'9
418	41'8	25'08	20'9	17'52	12'54	10'45	518	51'8	31'08	25'9	20'72	15'54	12'95
420	42'0	25'2	21'0	18'0	12'6	10'5	520	52'0	31'2	26'0	20'8	15'6	13'0
422	42'2	25'32	21'1	18'08	12'66	10'55	522	52'2	31'32	26'1	20'88	15'66	13'05
424	42'4	25'44	21'2	18'16	12'72	10'6	524	52'4	31'44	26'2	20'96	15'72	13'1
426	42'6	25'56	21'3	18'24	12'78	10'65	526	52'6	31'56	26'3	21'04	15'78	13'15
428	42'8	25'68	21'4	18'32	12'84	10'7	528	52'8	31'68	26'4	21'12	15'84	13'2
430	43'0	25'8	21'5	18'4	12'9	10'75	530	53'0	31'8	26'5	21'2	15'9	13'25
432	43'2	25'92	21'6	18'48	12'96	10'8	532	53'2	31'92	26'6	21'28	15'96	13'3
434	43'4	26'04	21'7	18'56	13'02	10'85	534	53'4	32'04	26'7	21'36	16'02	13'35
436	43'6	26'16	21'8	19'04	13'08	10'9	536	53'6	32'16	26'8	21'44	16'08	13'4
438	43'8	26'28	21'9	19'12	13'14	10'95	538	53'8	32'28	26'9	21'52	16'14	13'45
440	44'0	26'4	22'0	19'2	13'2	11'0	540	54'0	32'4	27'0	21'6	16'2	13'5
442	44'2	26'52	22'1	19'28	13'26	11'05	542	54'2	32'52	27'1	21'68	16'26	13'55
444	44'4	26'64	22'2	19'36	13'32	11'1	544	54'4	32'64	27'2	21'76	16'32	13'6
446	44'6	26'76	22'3	19'44	13'38	11'15	546	54'6	32'76	27'3	21'84	16'38	13'65
448	44'8	26'88	22'4	19'52	13'44	11'2	548	54'8	32'88	27'4	21'92	16'44	13'7

TABLE L.—CALORIFIC TABLES.—*Continued.*
(See Chapter 4.)

DIVISIONS OF ORDINARY EXPERIMENTAL METER.													
C. C. of Water.	6	10	12	15	20	24	C. C. of Water.	6	10	12	15	20	24
550	55°0	33°0	27°5	22°0	16°5	13°75	650	65°0	39°0	32°5	26°0	19°5	16°25
552	55°2	33°12	27°6	22°08	16°56	13°8	652	65°2	39°12	32°6	26°08	19°56	16°3
554	55°4	33°24	27°7	22°16	16°62	13°85	654	65°4	39°24	32°7	26°16	19°62	16°35
556	55°6	33°36	27°8	22°24	16°68	13°9	656	65°6	39°36	32°8	26°24	19°68	16°4
558	55°8	33°48	27°9	22°32	16°74	13°95	658	65°8	39°48	32°9	26°32	19°74	16°45
560	56°0	33°6	28°0	22°4	16°8	14°0	660	66°0	39°6	33°0	26°4	19°8	16°5
562	56°2	33°12	28°1	22°48	16°86	14°05	662	66°2	39°12	33°1	26°48	19°86	16°55
564	56°4	33°24	28°2	22°56	16°92	14°1	664	66°4	39°24	33°2	26°56	19°92	16°6
566	56°6	33°36	28°3	23°04	16°98	14°15	666	66°6	39°36	33°3	26°64	19°98	16°65
568	56°8	33°48	28°4	23°12	17°04	14°2	668	66°8	39°48	33°4	26°72	20°04	16°7
570	57°0	34°0	28°5	23°20	17°1	14°25	670	67°0	40°0	33°5	26°8	20°1	16°75
572	57°2	34°12	28°6	23°28	17°16	14°3	672	67°2	40°12	33°6	26°88	20°16	16°8
574	57°4	34°24	28°7	23°36	17°22	14°35	674	67°4	40°24	33°7	26°96	20°22	16°85
576	57°6	34°36	28°8	23°44	17°28	14°4	676	67°6	40°36	33°8	27°04	20°28	16°9
578	57°8	34°48	28°9	23°52	17°34	14°45	678	67°8	40°48	33°9	27°12	20°34	16°95
580	58°0	34°6	29°0	24°0	17°4	14°5	680	68°0	40°6	34°0	27°2	20°4	17°0
582	58°2	34°12	29°1	24°08	17°46	14°55	682	68°2	40°12	34°1	27°28	20°46	17°05
584	58°4	34°24	29°2	24°16	17°52	14°6	684	68°4	40°24	34°2	27°36	20°52	17°1
586	58°6	34°36	29°3	24°24	17°58	14°65	686	68°6	40°36	34°3	27°44	20°58	17°15
588	58°8	34°48	29°4	24°32	17°64	14°7	688	68°8	40°48	34°4	27°52	20°64	17°2
590	59°0	35°0	29°5	24°40	17°7	14°75	690	69°0	41°0	34°5	27°6	20°7	17°25
592	59°2	35°12	29°6	24°48	17°76	14°8	692	69°2	41°12	34°6	27°68	20°76	17°3
594	59°4	35°24	29°7	24°56	17°82	14°85	694	69°4	41°24	34°7	27°76	20°82	17°35
596	59°6	35°36	29°8	25°04	17°88	14°9	696	69°6	41°36	34°8	27°84	20°88	17°4
598	59°8	35°48	29°9	25°12	17°94	14°95	698	69°8	41°48	34°9	27°92	20°94	17°45
600	60°0	36°0	30°0	25°20	18°0	15°0	700	70°0	42°0	35°0	28°0	21°0	17°5
602	60°2	36°12	30°1	25°28	18°06	15°05	702	70°2	42°12	35°1	28°08	21°06	17°55
604	60°4	36°24	30°2	25°36	18°12	15°1	704	70°4	42°24	35°2	28°16	21°12	17°6
606	60°6	36°36	30°3	25°44	18°18	15°15	706	70°6	42°36	35°3	28°24	21°18	17°65
608	60°8	36°48	30°4	25°52	18°24	15°2	708	70°8	42°48	35°4	28°32	21°24	17°7
610	61°0	36°6	30°5	26°0	18°3	15°25	710	71°0	42°6	35°5	28°4	21°3	17°75
612	61°2	36°12	30°6	26°08	18°36	15°3	712	71°2	42°12	35°6	28°48	21°36	17°8
614	61°4	36°24	30°7	26°16	18°42	15°35	714	71°4	42°24	35°7	28°56	21°42	17°85
616	61°6	36°36	30°8	26°24	18°48	15°4	716	71°6	42°36	35°8	28°64	21°48	17°9
618	61°8	36°48	30°9	26°32	18°54	15°45	718	71°8	42°48	35°9	28°72	21°54	17°95
620	62°0	37°0	31°0	26°40	18°6	15°5	720	72°0	43°0	36°0	28°8	21°6	18°0
622	62°2	37°12	31°1	26°48	18°66	15°55	722	72°2	43°12	36°1	28°88	21°66	18°05
624	62°4	37°24	31°2	26°56	18°72	15°6	724	72°4	43°24	36°2	28°96	21°72	18°1
626	62°6	37°36	31°3	27°04	18°78	15°65	726	72°6	43°36	36°3	29°04	21°78	18°15
628	62°8	37°48	31°4	27°12	18°84	15°7	728	72°8	43°48	36°4	29°12	21°84	18°2
630	63°0	37°6	31°5	27°20	18°9	15°75	730	73°0	44°0	36°5	29°2	21°9	18°25
632	63°2	37°12	31°6	27°28	18°96	15°8	732	73°2	44°12	36°6	29°28	21°96	18°3
634	63°4	37°24	31°7	27°36	19°02	15°85	734	73°4	44°24	36°7	29°36	22°02	18°35
636	63°6	37°36	31°8	27°44	19°08	15°9	736	73°6	44°36	36°8	29°44	22°08	18°4
638	63°8	37°48	31°9	27°52	19°14	15°95	738	73°8	44°48	36°9	29°52	22°14	18°45
640	64°0	38°0	32°0	28°0	19°2	16°0	740	74°0	45°0	37°0	29°6	22°2	18°5
642	64°2	38°12	32°1	28°08	19°26	16°05	742	74°2	45°12	37°1	29°68	22°26	18°55
644	64°4	38°24	32°2	28°16	19°32	16°1	744	74°4	45°24	37°2	29°76	22°32	18°6
646	64°6	38°36	32°3	28°24	19°38	16°15	746	74°6	45°36	37°3	29°84	22°38	18°65
648	64°8	38°48	32°4	28°32	19°44	16°2	748	74°8	45°48	37°4	29°92	22°44	18°7

TABLE M.—AERORTHOMETER CORRECTION FOR SULPHUR TEST.

$$1. \text{ Gas Referees' Formula:— } R = r_1 \times \frac{h + r_1 - r_2}{h}$$

ALTERNATIVE FORMULA.

2. If R_2 is a higher number than R_1 , deduct from h the difference between R_2 and R_1 .

3. If R_2 is a lower number than R_1 , add to h the difference between R_2 and R_1 .

$$4. \text{ Then } \frac{.760 + \text{— (The difference between } R_2 \text{ and } R_1)}{Q} = Q^*$$

$$5. \text{ And } (Q + R_1) - 1.000 = R$$

TABLE OF THE VALUES OF Q (THE DIVISOR BEING ALWAYS $.760$)*

Dividend.	Q=	Dividend.	Q=	Dividend.	Q=
'730	'961	'751	'988	'772	1'016
'731	'962	'752	'989	'773	1'017
'732	'963	'753	'991	'774	1'018
'733	'964	'754	'992	'775	1'020
'734	'966	'755	'993	'776	1'021
'735	'967	'756	'995	'777	1'022
'736	'968	'757	'996	'778	1'024
'737	'970	'758	'997	'779	1'025
'738	'971	'759	'999	'780	1'026
'739	'972	'760	1'000	'781	1'028
'740	'974	'761	1'001	'782	1'029
'741	'975	'762	1'003	'783	1'030
'742	'976	'763	1'004	'784	1'032
'743	'978	'764	1'005	'785	1'033
'744	'979	'765	1'007	'786	1'034
'745	'980	'766	1'008	'787	1'036
'746	'982	'767	1'009	'788	1'037
'747	'983	'768	1'011	'789	1'038
'748	'984	'769	1'012	'790	1'039
'749	'986	'770	1'013	'791	1'041
'750	'987	'771	1'014	'792	1'042

EXPLANATION.

The correction for the reading of the Aerorthometer in the Sulphur Test is obtained by the Referees from formula one, where R be the corrected reading required, r_1 the actual aerorthometer reading, r_2 the reading of the companion tube, and h the mean height of the barometer in units of the aerorthometer scale, i. e., $.760$.

A quicker way to obtain R is from the formula five $(Q + R_1) - 1.000 = R$, Q being obtained from the table printed above, and the dividend to which Q corresponds in the table being found by either adding to or deducting from $.760$, according to rules two and three.

An example will explain more fully:

Let $r_1 = 1.008$ and $r_2 = 1.018$, $h = .760$.

Then the dividend in table = $.760 - 10(1.018 - 1.008) = 750$. *Rule 2.*

From the table, the Q corresponding to $.750 = .987$.

Then applying rule five $(.987 + 1.008) - 1.000 = R = .995$.

It will be seen that this method is simpler than the Referees' because it involves practically no calculation.

TABLE N.

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 2 Feet.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
1 80	+11'11	'92	+4'17	'04	-1'96	'16	-7'41
'81	+10'50	'93	+3'63	'05	-2'44	'17	-7'83
'82	+9'89	'94	+3'09	'06	-2'91	'18	-8'26
'83	+9'29	'95	+2'56	'07	-3'38	'19	-8 68
'84	+8'70	'96	+2'04	'08	-3'85	2'20	-9'09
'85	+8'11	'97	+1'52	'09	-4'31	'21	-9'50
'86	+7'53	'98	+1'01	2'10	-4'76	'22	-9'91
'87	+6'95	'99	+0'50	'11	-5'21	'23	-10'31
'88	+6'38	2'00	Nil.	'12	-5'66	'24	-10'71
'89	+5'82	'01	-0'50	'13	-6'10	'25	-11'11
1'90	+5'26	'02	-0'99	'14	-6'54		
'91	+4'71	'03	-1'48	'15	-6'98		

Meter Registering 5 Feet.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
4'50	+11'11	'71	+6'16	'92	+1'63	'13	-2'53
'51	+10'86	'72	+5'93	'93	+1'42	'14	-2 72
'52	+10'62	'73	+5'71	'94	+1'21	'15	-2'91
'53	+10'38	'74	+5'49	'95	+1'01	'16	-3'10
'54	+10'13	'75	+5'26	'96	+0'81	'17	-3'29
'55	+9'89	'76	+5'04	'97	+0'60	'18	-3 47
'56	+9'65	'77	+4'82	'98	+0'40	'19	-3'66
'57	+9'41	'78	+4'60	'99	+0'20	5'20	-3'85
'58	+9'17	'79	+4'38	5'00	Nil.	'21	-4'03
'59	+8'93	4'80	+4'17	'01	-0'20	'22	-4'21
4'60	+8'70	'81	+3'95	'02	-0'40	'23	-4'40
'61	+8'46	'82	+3'73	'03	-0'60	'24	-4'58
'62	+8'23	'83	+3'52	'04	-0'79	'25	-4'76
'63	+7'99	'84	+3'31	'05	-0'99	'26	-4'94
'64	+7'76	'85	+3'09	'06	-1'19	'27	-5'12
'65	+7'53	'86	+2'88	'07	-1'38	'28	-5'30
'66	+7'30	'87	+2'67	'08	-1'57	'29	-5'48
'67	+7'07	'88	+2'46	'09	-1'77	5'30	-5'66
'68	+6'84	'89	+2'25	5'10	-1'96	'31	-5'84
'69	+6'61	4'90	+2'04	'11	-2'15	'32	-6'02
4'70	+6'38	'91	+1'83	'12	-2'34	'33	-6'19

+ Signifies *Fast*.
- " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 5 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'34	— 6'37	'42	— 7'75	5'50	— 9'09	'58	— 10'39
'35	— 6'54	'43	— 7'92	'51	— 9'26	'59	— 10'55
'36	— 6'72	'44	— 8'09	'52	— 9'42	5'60	— 10'71
'37	— 6'89	'45	— 8'26	'53	— 9'59	'61	— 10'87
'38	— 7'06	'46	— 8'42	'54	— 9'75	'62	— 11'03
'39	— 7'24	'47	— 8'59	'55	— 9'91	'63	— 11'19
5'40	— 7'41	'48	— 8'76	'56	— 10'07		
'41	— 7'58	'48	— 8'93	'57	— 10'23		

Meter Registering 10 Feet.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
9'00	+ 11'11	'25	+ 8'11	9'50	+ 5'26	'75	+ 2'56
'01	+ 10'99	'26	+ 7'99	'51	+ 5'15	'76	+ 2'46
'02	+ 10'86	'27	+ 7'87	'52	+ 5'04	'77	+ 2'35
'03	+ 10'74	'28	+ 7'76	'53	+ 4'93	'78	+ 2'25
'04	+ 10'62	'29	+ 7'64	'54	+ 4'82	'79	+ 2'15
'05	+ 10'50	9'30	+ 7'53	'55	+ 4'71	9'80	+ 2'04
'06	+ 10'38	'31	+ 7'41	'56	+ 4'60	'81	+ 1'94
'07	+ 10'25	'32	+ 7'30	'57	+ 4'49	'82	+ 1'83
'08	+ 10'13	'33	+ 7'18	'58	+ 4'38	'83	+ 1'73
'09	+ 10'01	'34	+ 7'07	'59	+ 4'28	'84	+ 1'63
9'10	+ 9'89	'35	+ 6'95	9'60	+ 4'17	'85	+ 1'52
'11	+ 9'77	'36	+ 6'84	'61	+ 4'06	'86	+ 1'42
'12	+ 9'65	'37	+ 6'72	'62	+ 3'95	'87	+ 1'32
'13	+ 9'53	'38	+ 6'61	'63	+ 3'84	'88	+ 1'21
'14	+ 9'41	'39	+ 6'50	'64	+ 3'73	'89	+ 1'11
'15	+ 9'29	9'40	+ 6'38	'65	+ 3'63	9'90	+ 1'01
'16	+ 9'17	'41	+ 6'27	'66	+ 3'52	'91	+ 0'91
'17	+ 9'05	'42	+ 6'16	'67	+ 3'41	'92	+ 0'81
'18	+ 8'93	'43	+ 6'04	'68	+ 3'31	'93	+ 0'70
'19	+ 8'81	'44	+ 5'93	'69	+ 3'20	'94	+ 0'60
9'20	+ 8'70	'45	+ 5'82	9'70	+ 3'09	'95	+ 0'50
'21	+ 8'58	'46	+ 5'71	'71	+ 2'99	'96	+ 0'40
'22	+ 8'46	'47	+ 5'60	'72	+ 2'88	'97	+ 0'30
'23	+ 8'34	'48	+ 5'49	'73	+ 2'77	'98	+ 0'20
'24	+ 8'23	'49	+ 5'37	'74	+ 2'67	'99	+ 0'10

+ Signifies *Fast*,
— " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 10 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
10'00	Nil.	'32	— 3'10	'64	— 6'02	'96	— 8'76
'01	— 0'10	'33	— 3'19	'65	— 6'10	'97	— 8'84
'02	— 0'20	'34	— 3'29	'66	— 6'19	'98	— 8'93
'03	— 0'30	'35	— 3'38	'67	— 6'28	'99	— 9'01
'04	— 0'40	'36	— 3'47	'68	— 6'37	11'00	— 9'09
'05	— 0'50	'37	— 3'57	'69	— 6'45	'01	— 9'18
'06	— 0'60	'38	— 3'66	10'70	— 6'54	'02	— 9'26
'07	— 0'70	'39	— 3'75	'71	— 6'63	'03	— 9'34
'08	— 0'79	10'40	— 3'85	'72	— 6'72	'04	— 9'42
'09	— 0'89	'41	— 3'94	'73	— 6'80	'05	— 9'51
10'10	— 0'99	'42	— 4'03	'74	— 6'89	'06	— 9'59
'11	— 1'09	'43	— 4'12	'75	— 6'98	'07	— 9'67
'12	— 1'19	'44	— 4'21	'76	— 7'06	'08	— 9'75
'13	— 1'28	'45	— 4'31	'77	— 7'15	'09	— 9'83
'14	— 1'38	'46	— 4'40	'78	— 7'24	11'10	— 9'91
'15	— 1'48	'47	— 4'49	'79	— 7'32	'11	— 9'99
'16	— 1'57	'48	— 4'58	10'80	— 7'41	'12	— 10'07
'17	— 1'67	'49	— 4'67	'81	— 7'49	'13	— 10'15
'18	— 1'77	10'50	— 4'76	'82	— 7'58	'14	— 10'23
'19	— 1'86	'51	— 4'85	'83	— 7'66	'15	— 10'31
10'20	— 1'96	'52	— 4'94	'84	— 7'75	'16	— 10'39
'21	— 2'06	'53	— 5'03	'85	— 7'83	'17	— 10'47
'22	— 2'15	'54	— 5'12	'86	— 7'92	'18	— 10'55
'23	— 2'25	'55	— 5'21	'87	— 8'00	'19	— 10'63
'24	— 2'34	'56	— 5'30	'88	— 8'09	11'20	— 10'71
'25	— 2'44	'57	— 5'39	'89	— 8'17	'21	— 10'79
'26	— 2'53	'58	— 5'48	10'90	— 8'26	'22	— 10'87
'27	— 2'63	'59	— 5'57	'91	— 8'34	'23	— 10'95
'28	— 2'72	10'60	— 5'66	'92	— 8'42	'24	— 11'03
'29	— 2'82	'61	— 5'75	'93	— 8'51	'25	— 11'11
10'30	— 2'91	'62	— 5'84	'94	— 8'59		
'31	— 3'01	'63	— 5'93	'95	— 8'68		

+ Signifies *Fast*.
— " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 20 Feet.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
18'00	+11'11	'42	+8'58	'84	+6'16	'26	+3'84
'01	+11'05	'43	+8'52	'85	+6'10	'27	+3'78
'02	+10'99	'44	+8'46	'86	+6'04	'28	+3'73
'03	+10'92	'45	+8'40	'87	+5'98	'29	+3'68
'04	+10'86	'46	+8'34	'88	+5'93	19'30	+3'63
'05	+10'80	'47	+8'29	'89	+5'87	'31	+3'57
'06	+10'74	'48	+8'23	18'90	+5'82	'32	+3'52
'07	+10'68	'49	+8'17	'91	+5'76	'33	+3'46
'08	+10'62	18'50	+8'11	'92	+5'71	'34	+3'41
'09	+10'56	'51	+8'05	'93	+5'65	'35	+3'36
18'10	+10'50	'52	+7'99	'94	+5'60	'36	+3'31
'11	+10'44	'53	+7'93	'95	+5'54	'37	+3'25
'12	+10'38	'54	+7'87	'96	+5'49	'38	+3'20
'13	+10'31	'55	+7'82	'97	+5'43	'39	+3'14
'14	+10'25	'56	+7'76	'98	+5'37	19'40	+3'09
'15	+10'19	'57	+7'70	'99	+5'31	'41	+3'04
'16	+10'13	'58	+7'64	19'00	+5'26	'42	+2'99
'17	+10'07	'59	+7'59	'01	+5'20	'43	+2'93
'18	+10'01	18'60	+7'53	'02	+5'15	'44	+2'88
'19	+9'95	'61	+7'47	'03	+5'09	'45	+2'82
18'20	+9'89	'62	+7'41	'04	+5'04	'46	+2'77
'21	+9'83	'63	+7'36	'05	+4'98	'47	+2'72
'22	+9'77	'64	+7'30	'06	+4'93	'48	+2'67
'23	+9'71	'65	+7'24	'07	+4'87	'49	+2'61
'24	+9'65	'66	+7'18	'08	+4'82	19'50	+2'56
'25	+9'59	'67	+7'13	'09	+4'76	'51	+2'51
'26	+9'53	'68	+7'07	19'10	+4'71	'52	+2'46
'27	+9'47	'69	+7'01	'11	+4'65	'53	+2'40
'28	+9'41	18'70	+6'95	'12	+4'60	'54	+2'35
'29	+9'35	'71	+6'90	'13	+4'54	'55	+2'30
18'30	+9'29	'72	+6'84	'14	+4'49	'56	+2'25
'31	+9'23	'73	+6'78	'15	+4'43	'57	+2'20
'32	+9'17	'74	+6'72	'16	+4'38	'58	+2'15
'33	+9'11	'75	+6'66	'17	+4'33	'59	+2'09
'34	+9'05	'76	+6'61	'18	+4'28	19'60	+2'04
'35	+8'99	'77	+6'55	'19	+4'22	'61	+1'99
'36	+8'93	'78	+6'50	19'20	+4'17	'62	+1'94
'37	+8'87	'79	+6'44	'21	+4'11	'63	+1'88
'38	+8'81	18'80	+6'38	'22	+4'06	'64	+1'83
'39	+8'76	'81	+6'32	'23	+4'00	'65	+1'78
18'40	+8'70	'82	+6'27	'24	+3'95	'66	+1'73
'41	+8'64	'83	+6'21	'25	+3'89	'67	+1'68

+ Signifies *Fast*.
— " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 20 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'68	+ 1'63	'16	— 0'79	'96	— 4'58	'76	— 8'09
'69	+ 1'57	'18	— 0'89	'98	— 4'67	'78	— 8'17
19'70	+ 1'52	20'20	— 0'99	21'00	— 4'76	21'80	— 8'26
'71	+ 1'47	'22	— 1'09	'02	— 4'85	'82	— 8'34
'72	+ 1'42	'24	— 1'19	'04	— 4'94	'84	— 8'42
'73	+ 1'37	'26	— 1'28	'06	— 5'03	'86	— 8'51
'74	+ 1'32	'28	— 1'38	'08	— 5'12	'88	— 8'59
'75	+ 1'26	20'30	— 1'48	21'10	— 5'21	21'90	— 8'68
'76	+ 1'21	'32	— 1'57	'12	— 5'30	'92	— 8'76
'77	+ 1'16	'34	— 1'67	'14	— 5'39	'94	— 8'84
'78	+ 1'11	'36	— 1'77	'16	— 5'48	'96	— 8'93
'79	+ 1'06	'38	— 1'86	'18	— 5'57	'98	— 9'01
19'80	+ 1'01	20'40	— 1'96	21'20	— 5'66	22'00	— 9'09
'81	+ 0'96	'42	— 2'06	'22	— 5'75	'02	— 9'18
'82	+ 0'91	'44	— 2'15	'24	— 5'84	'04	— 9'26
'83	+ 0'86	'46	— 2'25	'26	— 5'93	'06	— 9'34
'84	+ 0'81	'48	— 2'34	'28	— 6'02	'08	— 9'42
'85	+ 0'75	20'50	— 2'44	21'30	— 6'10	22'10	— 9'51
'86	+ 0'70	'52	— 2'53	'32	— 6'19	'12	— 9'59
'87	+ 0'65	'54	— 2'63	'34	— 6'28	'14	— 9'67
'88	+ 0'60	'56	— 2'73	'36	— 6'37	'16	— 9'75
'89	+ 0'55	'58	— 2'82	'38	— 6'46	'18	— 9'83
19'90	+ 0'50	20'60	— 2'91	21'40	— 6'54	22'20	— 9'91
'91	+ 0'45	'62	— 3'01	'42	— 6'63	'22	— 9'99
'92	+ 0'40	'64	— 3'10	'44	— 6'72	'24	— 10'07
'93	+ 0'35	'66	— 3'19	'46	— 6'80	'26	— 10'15
'94	+ 0'30	'68	— 3'29	'48	— 6'89	'28	— 10'23
'95	+ 0'25	20'70	— 3'38	21'50	— 6'98	22'30	— 10'31
'96	+ 0'20	'72	— 3'47	'52	— 7'06	'32	— 10'39
'97	+ 0'15	'74	— 3'57	'54	— 7'15	'34	— 10'47
'98	+ 0'10	'76	— 3'66	'56	— 7'24	'36	— 10'55
'99	+ 0'05	'78	— 3'75	'58	— 7'32	'38	— 10'63
20'00	Nil.	20'80	— 3'85	21'60	— 7'41	22'40	— 10'71
'02	— 0'10	'82	— 3'94	'62	— 7'49	'42	— 10'79
'04	— 0'20	'84	— 4'03	'64	— 7'58	'44	— 10'87
'06	— 0'30	'86	— 4'12	'66	— 7'66	'46	— 10'95
'08	— 0'40	'88	— 4'21	'68	— 7'75	'48	— 11'03
20'10	— 0'50	20'90	— 4'31	21'70	— 7'83	22'50	— 11'11
'12	— 0'60	'92	— 4'40	'72	— 7'92		
'14	— 0'70	'94	— 4'49	'74	— 8'00		

+ Signifies *Fast*.
— " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 30 Feet.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
27'00	+11'11	'84	+7'76	'68	+4'60	'52	+1'63
'02	+11.03	'86	+7'68	28'70	+4'53	'54	+1'56
'04	+10'95	'88	+7'61	'72	+4'45	'56	+1'49
'06	+10.86	27'90	+7'53	'74	+4'38	'58	+1'42
'08	+10'78	'92	+7'45	'76	+4'31	29'60	+1'35
27'10	+10'70	'94	+7'38	'78	+4'24	'62	+1.28
'12	+10'62	'96	+7'30	28'80	+4'17	'64	+1'21
'14	+10'54	'98	+7'22	'82	+4'10	'66	+1'14
'16	+10'46	28'00	+7'14	'84	+4'02	'68	+1'08
'18	+10'38	'02	+7'07	'86	+3'95	29'70	+1'01
27'20	+10'30	'04	+6'99	'88	+3'88	'72	+0'94
'22	+10'21	'06	+6'92	28'90	+3'81	'74	+0'88
'24	+10'13	'08	+6'84	'92	+3'73	'76	+0'81
'26	+10'05	28'10	+6'76	'94	+3'66	'78	+0'74
'28	+9'97	'12	+6'69	'96	+3'59	29'80	+0'67
27'30	+9'89	'14	+6'61	'98	+3'52	'82	+0.60
'32	+9'81	'16	+6'53	29'00	+3'45	'84	+0'53
'34	+9'73	'18	+6'46	'02	+3'38	'86	+0'47
'36	+9'65	28'20	+6'38	'04	+3'31	'88	+0'40
'38	+9'57	'22	+6'31	'06	+3'24	29'90	+0'33
27'40	+9'49	'24	+6'23	'08	+3'16	'92	+0'26
'42	+9'41	'26	+6'16	29'10	+3'09	'94	+0'20
'44	+9'33	'28	+6'08	'12	+3'02	'96	+0'13
'46	+9'25	28'30	+6'01	'14	+2'95	'98	+0'07
'48	+9'17	'32	+5'93	'16	+2'88	30'00	Nil.
27'50	+9'09	'34	+5'86	'18	+2'81	'02	+0'07
'52	+9.01	'36	+5'78	29'20	+2'74	'04	+0'13
'54	+8'93	'38	+5'71	'22	+2'67	'06	+0'20
'56	+8'85	28'40	+5'63	'24	+2'60	'08	+0'27
'58	+8'78	'42	+5'56	'26	+2'53	30'10	+0'33
27'60	+8'70	'44	+5'49	'28	+2'46	'12	+0'40
'62	+8'62	'46	+5'41	29'30	+2'39	'14	+0'47
'64	+8'54	'48	+5'34	'32	+2'32	'16	+0'53
'66	+8'46	28'50	+5'26	'34	+2'25	'18	+0'60
'68	+8'38	'52	+5'19	'36	+2'18	30'20	+0'66
27'70	+8'31	'54	+5'11	'38	+2'11	'22	+0'73
'72	+8'23	'56	+5'04	29'40	+2'04	'24	+0'79
'74	+8.15	'58	+4'96	'42	+1'97	'26	+0'86
'76	+8'07	28'60	+4'89	'44	+1'90	'28	+0'92
'78	+7'99	'62	+4'82	'46	+1'83	30'30	+0'99
27'80	+7'92	'64	+4'75	'48	+1'76	'32	+1'06
'82	+7'84	'66	+4'67	29'50	+1'69	'34	+1'12

+ Signifies *Fast*.— " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 30 Feet.—*Continued.*

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'36	— 1'19	'22	— 3'91	'08	— 6.48	'94	— 8'93
'38	— 1'26	'24	— 3'97	32'10	— 6'54	'96	— 8'99
30'40	— 1'32	'26	— 4'03	'12	— 6'60	'98	— 9'04
'42	— 1'38	'28	— 4'09	'14	— 6'66	33'00	— 9'09
'44	— 1'44	31'30	— 4'16	'16	— 6'72	'02	— 9'15
'46	— 1'51	'32	— 4'22	'18	— 6'77	'04	— 9'20
'48	— 1'57	'34	— 4'28	32'20	— 6'83	'06	— 9'26
30'50	— 1'64	'36	— 4'34	'22	— 6'89	'08	— 9'31
'52	— 1'71	'38	— 4'40	'24	— 6'95	33'10	— 9'36
'54	— 1'77	31'40	— 4'46	'26	— 7.01	'12	— 9'42
'56	— 1'83	'42	— 4'52	'28	— 7'07	'14	— 9'47
'58	— 1'89	'44	— 4'58	32'30	— 7'12	'16	— 9'53
30'60	— 1'96	'46	— 4'64	'32	— 7'18	'18	— 9'59
'62	— 2'02	'48	— 4'70	'34	— 7'24	33'20	— 9'64
'64	— 2'09	31'50	— 4'76	'36	— 7'30	'22	— 9'70
'66	— 2'15	'52	— 4'82	'38	— 7'36	'24	— 9'75
'68	— 2'22	'54	— 4'88	32'40	— 7'41	'26	— 9'81
30'70	— 2'28	'56	— 4'94	'42	— 7'47	'28	— 9'86
'72	— 2'34	'58	— 5'00	'44	— 7'53	33'30	— 9'91
'74	— 2'40	31'60	— 5'06	'46	— 7'59	'32	— 9'96
'76	— 2'47	'62	— 5'12	'48	— 7'64	'34	— 10'01
'78	— 2'53	'64	— 5'18	32'50	— 7'70	'36	— 10'07
30'80	— 2'60	'66	— 5'24	'52	— 7'76	'38	— 10'12
'82	— 2'66	'68	— 5'30	'54	— 7'82	33'40	— 10'18
'84	— 2.72	31'70	— 5'36	'56	— 7'87	'42	— 10'23
'86	— 2'78	'72	— 5'42	'58	— 7'93	'44	— 10'28
'88	— 2.85	'74	— 5.48	32.60	— 7'98	'46	— 10'34
30'90	— 2'91	'76	— 5'54	'62	— 8'04	'48	— 10'39
'92	— 2'97	'78	— 5'60	'64	— 8'10	33'50	— 10'45
'94	— 3'04	31'80	— 5'66	'66	— 8'15	'52	— 10'50
'96	— 3'10	'82	— 5'72	'68	— 8'21	'54	— 10'55
'98	— 3'16	'84	— 5'78	32'70	— 8'26	'56	— 10'61
31'00	— 3'22	'86	— 5'84	'72	— 8'32	'58	— 10'66
'02	— 3'29	'88	— 5'90	'74	— 8'37	33'60	— 10'71
'04	— 3'35	31'90	— 5'96	'76	— 8'43	'62	— 10'76
'06	— 3'42	'92	— 6'02	'78	— 8'49	'64	— 10'82
'08	— 3'48	'94	— 6'08	32'80	— 8'54	'66	— 10'87
31'10	— 3'54	'96	— 6'13	'82	— 8'60	'68	— 10'93
'12	— 3'60	'98	— 6'19	'84	— 8'66	33'70	— 10'98
'14	— 3'66	32'00	— 6'25	'86	— 8'71	'72	— 11'03
'16	— 3'72	'02	— 6'31	'88	— 8'77	'74	— 11'09
'18	— 3'79	'04	— 6'37	32.90	— 8'82	'76	— 11'14
31'20	— 3'85	'06	— 6'42	'92	— 8'87	'78	— 11'19

+ Signifies *Fast*.— " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 40 Feet.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
36'00	+11'11	'84	+8'58	'68	+6'16	'52	+3'84
'02	+11'05	'86	+8'52	37'70	+6'10	'54	+3'78
'04	+10'99	'88	+8'46	'72	+6'04	'56	+3'73
'06	+10'92	36'90	+8'40	'74	+5'98	'58	+3'68
'08	+10'86	'92	+8'34	'76	+5'93	38'60	+3'63
36'10	+10'80	'94	+8'29	'78	+5'87	'62	+3'57
'12	+10'74	'96	+8'23	37'80	+5'82	'64	+3'52
'14	+10'68	'98	+8'17	'82	+5'76	'66	+3'46
'16	+10'62	37'00	+8'11	'84	+5'71	'68	+3'41
'18	+10'56	'02	+8'05	'86	+5'65	38'70	+3'36
36'20	+10'50	'04	+7'99	'88	+5'60	'72	+3'31
'22	+10'44	'06	+7'93	37'90	+5'54	'74	+3'25
'24	+10'38	'08	+7'87	'92	+5'49	'76	+3'20
'26	+10'31	37'10	+7'82	'94	+5'43	'78	+3'14
'28	+10'25	'12	+7'76	'96	+5'37	38'80	+3'09
36'30	+10'19	'14	+7'70	'98	+5'31	'82	+3'04
'32	+10'13	'16	+7'64	38'00	+5'26	'84	+2'99
'34	+10'07	'18	+7'59	'02	+5'20	'86	+2'93
'36	+10'01	37'20	+7'53	'04	+5'15	'88	+2'88
'38	+9'95	'22	+7'47	'06	+5'09	38'90	+2'82
36'40	+9'89	'24	+7'41	'08	+5'04	'92	+2'77
'42	+9'83	'26	+7'36	38'10	+4'98	'94	+2'72
'44	+9'77	'28	+7'30	'12	+4'93	'96	+2'67
'46	+9'71	37'30	+7'24	'14	+4'87	'98	+2'61
'48	+9'65	'32	+7'18	'16	+4'82	39'00	+2'56
36'50	+9'59	'34	+7'13	'18	+4'76	'02	+2'51
'52	+9'53	'36	+7'07	38'20	+4'71	'04	+2'46
'54	+9'47	'38	+7'01	'22	+4'65	'06	+2'40
'56	+9'41	37'40	+6'95	'24	+4'60	'08	+2'35
'58	+9'35	'42	+6'90	'26	+4'54	39'10	+2'30
36'60	+9'29	'44	+6'84	'28	+4'49	'12	+2'25
'62	+9'23	'46	+6'78	38'30	+4'44	'14	+2'20
'64	+9'17	'48	+6'72	'32	+4'38	'16	+2'15
'66	+9'11	37'50	+6'66	'34	+4'33	'18	+2'09
'68	+9'05	'52	+6'61	'36	+4'28	39'20	+2'04
36'70	+8'99	'54	+6'55	'38	+4'22	'22	+1'99
'72	+8'93	'56	+6'50	38'40	+4'17	'24	+1'94
'74	+8'87	'58	+6'44	'42	+4'11	'26	+1'88
'76	+8'81	37'60	+6'38	'44	+4'06	'28	+1'83
'78	+8'76	'62	+6'32	'46	+4'00	39'30	+1'78
36'80	+8'70	'64	+6'27	'48	+3'95	'32	+1'73
'82	+8'64	'66	+6'21	38'50	+3'90	'34	+1'68

+ Signifies *Fast*
— " *Slow.*

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 40 Feet.—*Continued.*

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'63	+ 1'63	40'20	— 0'50	'04	— 2'53	'88	— 4'49
'38	+ 1.57	'22	— 0'55	'06	— 2'58	41'90	— 4'54
39'40	+ 1'52	'24	— 0'60	'08	— 2'63	'92	— 4'58
'42	+ 1'47	'26	— 0'65	41'10	— 2'68	'94	— 4'63
'44	+ 1'42	'28	— 0'70	'12	— 2'72	'96	— 4'67
'46	+ 1'37	40'30	— 0'75	'14	— 2'78	'98	— 4'72
'48	+ 1'32	'32	— 0'79	'16	— 2'82	42'00	— 4'76
39'50	+ 1'26	'34	— 0'84	'18	— 2'87	'02	— 4'81
'52	+ 1'21	'36	— 0'89	41'20	— 2'91	'04	— 4'85
'54	+ 1'16	'38	— 0'94	'22	— 2'96	'06	— 4'90
'56	+ 1'11	40'40	— 0'99	'24	— 3'01	'08	— 4'94
'58	+ 1'06	'42	— 1'04	'26	— 3'06	42'10	— 4'99
39'60	+ 1'01	'44	— 1'09	'28	— 3'10	'12	— 5'03
'62	+ 0'96	'46	— 1'14	41'30	— 3'15	'14	— 5'08
'64	+ 0'91	'48	— 1'19	'32	— 3'19	'16	— 5'12
'66	+ 0'86	40'50	— 1'24	'34	— 3'24	'18	— 5'17
'68	+ 0'81	'52	— 1'28	'36	— 3'29	42'20	— 5'21
39'70	+ 0'75	'54	— 1'33	'38	— 3'34	'22	— 5'26
'72	+ 0'70	'56	— 1'38	41'40	— 3'38	'24	— 5'30
'74	+ 0'65	'58	— 1'43	'42	— 3'43	'26	— 5'35
'76	+ 0'60	40'60	— 1'48	'44	— 3'47	'28	— 5'39
'78	+ 0.55	'62	— 1'53	'46	— 3'52	42'30	— 5'44
39'80	+ 0.50	'64	— 1'57	'48	— 3'57	'32	— 5'48
'82	+ 0'45	'66	— 1'62	41'50	— 3'61	'34	— 5'53
'84	+ 0'40	'68	— 1'67	'52	— 3'66	'36	— 5'57
'86	+ 0'35	40'70	— 1'72	'54	— 3'71	'38	— 5'62
'88	+ 0'30	'72	— 1'77	'56	— 3'75	42'40	— 5'66
39'90	+ 0'25	'74	— 1'82	'58	— 3'80	'42	— 5'71
'92	+ 0'20	'76	— 1'86	41'60	— 3'85	'44	— 5'75
'94	+ 0'15	'78	— 1'91	'62	— 3'90	'46	— 5'80
'96	+ 0'10	40'80	— 1'96	'64	— 3'94	'48	— 5'84
'98	+ 0'05	'82	— 2'01	'66	— 3'99	42'50	— 5'88
40'00	Nil.	'84	— 2'06	'68	— 4'03	'52	— 5'93
'02	— 0'05	'86	— 2'10	41'70	— 4'08	'54	— 5'98
'04	— 0'10	'88	— 2'15	'72	— 4'12	'56	— 6'02
'06	— 0'15	40'90	— 2'20	'74	— 4'17	'58	— 6'06
'08	— 0'20	'92	— 2'25	'76	— 4'21	42'60	— 6'10
40'10	— 0'25	'94	— 2'30	'78	— 4'26	'62	— 6'15
'12	— 0'30	'96	— 2'34	41'80	— 4'31	'64	— 6'19
'14	— 0'35	'98	— 2'39	'82	— 4'36	'66	— 6'24
'16	— 0'40	41'00	— 2'44	'84	— 4'40	'68	— 6'28
'18	— 0'45	'02	— 2'49	'86	— 4'45	42'70	— 6'33

+ Signifies *Fast.*— " *Slow.*

TABLE N.—Continued.

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 40 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'72	— 6'37	43'30	— 7'62	'88	— 8'84	'46	— 10'03
'74	— 6'41	'32	— 7'66	43'90	— 8'89	'48	— 10'07
'76	— 6'45	'34	— 7'71	'92	— 8'93	44'50	— 10'11
'78	— 6'50	'36	— 7'75	'94	— 8'97	'52	— 10'15
42'80	— 6'54	'38	— 7'79	'96	— 9'01	'54	— 10'19
'82	— 6'59	43'40	— 7'83	'98	— 9'05	'56	— 10'23
'84	— 6'63	'42	— 7'88	44'00	— 9'09	'58	— 10'27
'86	— 6'68	'44	— 7'92	'02	— 9'14	44'60	— 10'31
'88	— 6'72	'46	— 7'96	'04	— 9'18	'62	— 10'35
42'90	— 6'76	'48	— 8'00	'06	— 9'22	'64	— 10'39
'92	— 6'80	43'50	— 8'05	'08	— 9'26	'66	— 10'43
'94	— 6'85	'52	— 8'09	44'10	— 9'30	'68	— 10'47
'96	— 6'89	'54	— 8'13	'12	— 9'34	44'70	— 10'51
'98	— 6'94	'56	— 8'17	'14	— 9'38	'72	— 10'55
43'00	— 6'98	'58	— 8'22	'16	— 9'42	'74	— 10'59
'02	— 7'02	43'60	— 8'26	'18	— 9'47	'76	— 10'63
'04	— 7'06	'62	— 8'30	44'20	— 9'51	'78	— 10'67
'06	— 7'11	'64	— 8'34	'22	— 9'55	44'80	— 10'71
'08	— 7'15	'66	— 8'38	'24	— 9'59	'82	— 10'75
43'10	— 7'20	'68	— 8'42	'26	— 9'63	'84	— 10'79
'12	— 7'24	43'70	— 8'47	'28	— 9'67	'86	— 10'84
'14	— 7'28	'72	— 8'51	44'30	— 9'71	'88	— 10'87
'16	— 7'32	'74	— 8'55	'32	— 9'75	44'90	— 10'91
'18	— 7'37	'76	— 8'59	'34	— 9'79	'92	— 10'95
43'20	— 7'41	'78	— 8'64	'36	— 9'83	'94	— 10'99
'22	— 7'45	43'80	— 8'68	'38	— 9'87	'96	— 11'03
'24	— 7'49	'82	— 8'72	44'40	— 9'91	'98	— 11'07
'26	— 7'54	'84	— 8'76	'42	— 9'95	45'00	— 11'11
'28	— 7'58	'86	— 8'80	'44	— 9'99		

Meter Registering 50 Feet.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
45'00	+ 11'11	'08	+ 10'91	'16	+ 10'72	'24	+ 10'52
'02	+ 11'06	45'10	+ 10'86	'18	+ 10'67	'26	+ 10'48
'04	+ 11'01	'12	+ 10'81	45'20	+ 10'62	'28	+ 10'43
'06	+ 10'96	'14	+ 10'76	'22	+ 10'57	45'30	+ 10'38

+ Signifies *Fast*
— " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 50 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'32	+10'33	'16	+8'32	47'00	+6'38	'84	+4'51
'34	+10'28	'18	+8'28	'02	+5'34	'86	+4'47
'36	+10'23	46'20	+8'23	'04	+6'29	'88	+4'42
'38	+10'18	'22	+8'18	'06	+6'25	47'90	+4'38
45'40	+10'13	'24	+8'13	'08	+6'20	'92	+4'34
'42	+10'08	'26	+8'09	47'10	+6'16	'94	+4'30
'44	+10'03	'28	+8'04	'12	+6'11	'96	+4'25
'46	+9'99	46'30	+7'99	'14	+6'07	'98	+4'21
'48	+9'94	'32	+7'94	'16	+6.02	48'00	+4'17
45'50	+9'89	'34	+7'90	'18	+5'98	'02	+4'13
'52	+9'84	'36	+7'85	47'20	+5'93	'04	+4'08
'54	+9'79	'38	+7'81	'22	+5'89	'06	+4'04
'56	+9'75	46'40	+7'76	'24	+5'84	'08	+3'99
'58	+9'70	'42	+7'71	'26	+5'80	48'10	+3'95
45'60	+9'65	'44	+7'67	'28	+5'75	'12	+3'91
'62	+9'60	'46	+7'62	47'30	+5'71	'14	+3'86
'64	+9'55	'48	+7'58	'32	+5'67	'16	+3'82
'66	+9'51	46'50	+7'53	'34	+5'62	'18	+3'77
'68	+9'46	'52	+7'48	'36	+5'58	48'20	+3'73
45'70	+9'41	'54	+7'44	'38	+5'53	'22	+3'69
'72	+9'36	'56	+7'39	47'40	+5'49	'24	+3'65
'74	+9'31	'58	+7'35	'42	+5'44	'26	+3'60
'76	+9'27	46'60	+7'30	'44	+5'40	'28	+3'56
'78	+9'22	'62	+7'25	'46	+5'35	48'30	+3'52
45'80	+9'17	'64	+7'21	'48	+5'31	'32	+3'48
'82	+9'12	'66	+7'16	47'50	+5'26	'34	+3'44
'84	+9'07	'68	+7'12	'52	+5'22	'36	+3'39
'86	+9'03	46'70	+7'07	'54	+5'17	'38	+3'35
'88	+8'98	'72	+7'02	'56	+5'13	48'40	+3'31
45'90	+8'93	'74	+6'98	'58	+5'08	'42	+3'27
'92	+8'88	'76	+6'93	47'60	+5'04	'44	+3'22
'94	+8'84	'78	+6'89	'62	+5'00	'46	+3'18
'96	+8'79	46'80	+6'84	'64	+4'95	'48	+3'13
'98	+8'75	'82	+6'79	'66	+4'91	48'50	+3'09
46'00	+8'70	'84	+6'75	'68	+4'86	'52	+3'05
'02	+8'65	'86	+6'70	47'70	+4'82	'54	+3'01
'04	+8'60	'88	+6'66	'72	+4'78	'56	+2'96
'06	+8'56	46'90	+6'61	'74	+4'73	'58	+2'92
'08	+8'51	'92	+6'56	'76	+4'69	48'60	+2'88
46'10	+8'46	'94	+6'52	'78	+4'64	'62	+2'84
'12	+8'41	'96	+6'47	47'80	+4'60	'64	+2'80
'14	+8'37	'98	+6'43	'82	+4'56	'66	+2'75

+ Signifies *Fast*.— " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 50 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'68	+ 2'71	'52	+ 0'97	'36	— 0'71	51'20	— 2'34
48'70	+ 2'67	'54	+ 0'97	'38	— 0'75	'22	— 2'38
'72	+ 2'63	'56	+ 0'81	50'40	— 0'79	'24	— 2'42
'74	+ 2'59	'58	+ 0'81	'42	— 0'83	'26	— 2'45
'76	+ 2'54	49'60	+ 0'87	'44	— 0'87	'28	— 2'49
'78	+ 2'50	'62	+ 0'71	'46	— 0'91	51'30	— 2'53
48'80	+ 2'46	'64	+ 0'71	'48	— 0'95	'32	— 2'57
'82	+ 2'42	'66	+ 0'66	50'50	— 0'99	'34	— 2'61
'84	+ 2'38	'68	+ 0'61	'52	— 1'03	'36	— 2'65
'86	+ 2'33	49'70	+ 0'61	'54	— 1'07	'38	— 2'69
'88	+ 2'29	'72	+ 0'61	'56	— 1'11	51'40	— 2'72
48'90	+ 2'25	'74	+ 0'61	'58	— 1'15	'42	— 2'76
'92	+ 2'21	'76	+ 0'45	50'60	— 1'19	'44	— 2'80
'94	+ 2'17	'78	+ 0'44	'62	— 1'23	'46	— 2'83
'96	+ 2'12	49'80	+ 0'40	'64	— 1'27	'48	— 2'87
'98	+ 2'08	'82	+ 0'36	'66	— 1'30	51'50	— 2'91
49'00	+ 2'04	'84	+ 0'32	'68	— 1'34	'52	— 2'95
'02	+ 2'00	'86	+ 0'28	50'70	— 1'38	'54	— 2'99
'04	+ 1'96	'88	+ 0'24	'72	— 1'42	'56	— 3'02
'06	+ 1'91	49'90	+ 0'20	'74	— 1'46	'58	— 3'06
'08	+ 1'87	'92	+ 0'16	'76	— 1'49	51'60	— 3'10
49'10	+ 1'83	'94	+ 0'12	'78	— 1'53	'62	— 3'14
'12	+ 1'79	'96	+ 0'08	50'80	— 1'57	'64	— 3'18
'14	+ 1'75	'98	+ 0'04	'82	— 1'61	'66	— 3'21
'16	+ 1'71	50'00	Nil.	'84	— 1'65	'68	— 3'25
'18	+ 1'67	'02	— 0'04	'86	— 1'69	51'70	— 3'29
49'20	+ 1'63	'04	— 0'08	'88	— 1'73	'72	— 3'33
'22	+ 1'59	'06	— 0'12	50'90	— 1'77	'74	— 3'36
'24	+ 1'55	'08	— 0'16	'92	— 1'81	'76	— 3'40
'26	+ 1'50	50'10	— 0'20	'94	— 1'85	'78	— 3'43
'28	+ 1'46	'12	— 0'24	'96	— 1'88	51'80	— 3'47
49'30	+ 1'42	'14	— 0'28	'98	— 1'92	'82	— 3'51
'32	+ 1'38	'16	— 0'32	51'00	— 1'96	'84	— 3'55
'34	+ 1'34	'18	— 0'36	'02	— 2'00	'86	— 3'58
'36	+ 1'29	50'20	— 0'40	'04	— 2'04	'88	— 3'62
'38	+ 1'25	'22	— 0'44	'06	— 2'07	51'90	— 3'66
49'40	+ 1'21	'24	— 0'48	'08	— 2'11	'92	— 3'70
'42	+ 1'17	'26	— 0'52	51'10	— 2'15	'94	— 3'74
'44	+ 1'13	'28	— 0'56	'12	— 2'19	'96	— 3'77
'46	+ 1'09	50'30	— 0'60	'14	— 2'23	'98	— 3'81
'48	+ 1'05	'32	— 0'64	'16	— 2'26	52'00	— 3'85
49'50	+ 1'01	'34	— 0'68	'18	— 2'30	'05	— 3'94

+ Signifies *Fast*.— " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 50 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'10	— 4'03	'15	— 5'93	'20	— 7'75	'25	— 9'51
'15	— 4'12	'20	— 6'02	'25	— 7'83	'30	— 9'59
'20	— 4'21	'25	— 6'10	'30	— 7'92	'35	— 9'67
'25	— 4'31	'30	— 6'19	'35	— 8'00	'40	— 9'75
'30	— 4'40	'35	— 6'28	'40	— 8'09	'45	— 9'83
'35	— 4'49	'40	— 6'37	'45	— 8'17	55'50	— 9'91
'40	— 4'58	'45	— 6'45	54'50	— 8'26	'55	— 9'99
'45	— 4'67	53'50	— 6'54	'55	— 8'34	'60	— 10'07
52'50	— 4'76	'55	— 6'63	'60	— 8'42	'65	— 10'15
'55	— 4'85	'60	— 6'72	'65	— 8'51	'70	— 10'23
'60	— 4'94	'65	— 6'80	'70	— 8'59	'75	— 10'31
'65	— 5'03	'70	— 6'89	'75	— 8'68	'80	— 10'39
'70	— 5'12	'75	— 6'98	'80	— 8'76	'85	— 10'47
'75	— 5'21	'80	— 7'06	'85	— 8'84	'90	— 10'55
'80	— 5'30	'85	— 7'15	'90	— 8'93	'95	— 10'63
'85	— 5'39	'90	— 7'24	'95	— 9'01	56'00	— 10'71
'90	— 5'48	'95	— 7'32	55'00	— 9'09	'05	— 10'79
'95	— 5'57	54'00	— 7'41	'05	— 9'18	'10	— 10'87
53'00	— 5'66	'05	— 7'49	'10	— 9'26	'15	— 10'95
'05	— 5'75	'10	— 7'58	'15	— 9'34	'20	— 11'03
'10	— 5'84	'15	— 7'66	'20	— 9'42	'25	— 11'11

Meter Registering 100 Feet.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
90'00	+ 11'11	'60	+ 10'38	'20	+ 9'65	'80	+ 8'93
'05	+ 11'05	'65	+ 10'31	'25	+ 9'59	'85	+ 8'87
'10	+ 10'99	'70	+ 10'25	'30	+ 9'53	'90	+ 8'81
'15	+ 10'92	'75	+ 10'19	'35	+ 9'47	'95	+ 8'76
'20	+ 10'86	'80	+ 10'13	'40	+ 9'41	92'00	+ 8'70
'25	+ 10'80	'85	+ 10'07	'45	+ 9'35	'05	+ 8'64
'30	+ 10'74	'90	+ 10'01	91'50	+ 9'29	'10	+ 8'58
'35	+ 10'68	'95	+ 9'95	'55	+ 9'23	'15	+ 8'52
'40	+ 10'62	91'00	+ 9'89	'60	+ 9'17	'20	+ 8'46
'45	+ 10'56	'05	+ 9'83	'65	+ 9'11	'25	+ 8'40
90'50	+ 10'50	'10	+ 9'77	'70	+ 9'05	'30	+ 8'34
'55	+ 10'44	'15	+ 9'71	'75	+ 8'99	'35	+ 8'29

+ Signifies *Fast*.
— " *Slow*.

TABLE N.—Continued.

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 100 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'40	+ 8'23	94'50	+ 5'82	'60	+ 3'52	'70	+ 1'32
'45	+ 8'17	'55	+ 5'76	'65	+ 3'46	'75	+ 1'26
92'50	+ 8'11	'60	+ 5'71	'70	+ 3'41	'80	+ 1'21
'55	+ 8'05	'65	+ 5'65	'75	+ 3'36	'85	+ 1'16
'60	+ 7'99	'70	+ 5'60	'80	+ 3'31	'90	+ 1'11
'65	+ 7'93	'75	+ 5'54	'85	+ 3'25	'95	+ 1'06
'70	+ 7'87	'80	+ 5'49	'90	+ 3'20	99'00	+ 1'01
'75	+ 7'82	'85	+ 5'43	'95	+ 3'14	'05	+ 0'96
'80	+ 7'76	'90	+ 5'37	97'00	+ 3'09	'10	+ 0'91
'85	+ 7'70	'95	+ 5'31	'05	+ 3'04	'15	+ 0'86
'90	+ 7'64	95'00	+ 5'26	'10	+ 2'99	'20	+ 0'81
'95	+ 7'59	'05	+ 5'20	'15	+ 2'93	'25	+ 0'75
93'00	+ 7'53	'10	+ 5'15	'20	+ 2'88	'30	+ 0'70
'05	+ 7'47	'15	+ 5'09	'25	+ 2'82	'35	+ 0'65
'10	+ 7'41	'20	+ 5'04	'30	+ 2'77	'40	+ 0'60
'15	+ 7'36	'25	+ 4'98	'35	+ 2'72	'45	+ 0'55
'20	+ 7'30	'30	+ 4'93	'40	+ 2'67	99'50	+ 0'50
'25	+ 7'24	'35	+ 4'87	'45	+ 2'61	'55	+ 0'45
'30	+ 7'18	'40	+ 4'82	97'50	+ 2'56	'60	+ 0'40
'35	+ 7'13	'45	+ 4'76	'55	+ 2'51	'65	+ 0'35
'40	+ 7'07	95'50	+ 4'71	'60	+ 2'46	'70	+ 0'30
'45	+ 7'01	'55	+ 4'65	'65	+ 2'40	'75	+ 0'25
93'50	+ 6'95	'60	+ 4'60	'70	+ 2'35	'80	+ 0'20
'55	+ 6'90	'65	+ 4'54	'75	+ 2'30	'85	+ 0'15
'60	+ 6'84	'70	+ 4'49	'80	+ 2'25	'90	+ 0'10
'65	+ 6'78	'75	+ 4'43	'85	+ 2'20	'95	+ 0'05
'70	+ 6'72	'80	+ 4'38	'90	+ 2'15	100'00	Nil.
'75	+ 6'66	'85	+ 4'33	'95	+ 2'09	'05	+ 0'05
'80	+ 6'61	'90	+ 4'28	98'00	+ 2'04	'10	+ 0'10
'85	+ 6'55	'95	+ 4'22	'05	+ 1'99	'15	+ 0'15
'90	+ 6'50	96'00	+ 4'17	'10	+ 1'94	'20	+ 0'20
'95	+ 6'44	'05	+ 4'11	'15	+ 1'88	'25	+ 0'25
94'00	+ 6'38	'10	+ 4'06	'20	+ 1'83	'30	+ 0'30
'05	+ 6'32	'15	+ 4'00	'25	+ 1'78	'35	+ 0'35
'10	+ 6'27	'20	+ 3'95	'30	+ 1'73	'40	+ 0'40
'15	+ 6'21	'25	+ 3'89	'35	+ 1'68	'45	+ 0'45
'20	+ 6'16	'30	+ 3'84	'40	+ 1'63	100'50	+ 0'50
'25	+ 6'10	'35	+ 3'78	'45	+ 1'57	'55	+ 0'55
'30	+ 6'04	'40	+ 3'73	98'50	+ 1'52	'60	+ 0'60
'35	+ 5'98	'45	+ 3'68	'55	+ 1'47	'65	+ 0'65
'40	+ 5'93	96'50	+ 3'63	'60	+ 1'42	'70	+ 0'70
'45	+ 5'87	'55	+ 3'57	'65	+ 1'37	'75	+ 0'75

+ Signifies *Fast*.— " *Slow*.

TABLE N.—Continued.

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 100 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'80	— 0'79	'90	— 2'82	105'00	— 4'76	'10	— 6'63
'85	— 0'84	'95	— 2'87	'05	— 4'81	'15	— 6'68
'90	— 0'89	103'00	— 2'91	'10	— 4'85	'20	— 6'72
'95	— 0'94	'05	— 2'96	'15	— 4'90	'25	— 6'76
101'00	— 0'99	'10	— 3'01	'20	— 4'94	'30	— 6'80
'05	— 1'04	'15	— 3'06	'25	— 4'99	'35	— 6'85
'10	— 1'09	'20	— 3'10	'30	— 5'03	'40	— 6'89
'15	— 1'14	'25	— 3'15	'35	— 5'08	'45	— 6'94
'20	— 1'19	'30	— 3'19	'40	— 5'12	107'50	— 6'98
'25	— 1'24	'35	— 3'24	'45	— 5'17	'55	— 7'02
'30	— 1'28	'40	— 3'29	105'50	— 5'21	'60	— 7'06
'35	— 1'33	'45	— 3'34	'55	— 5'26	'65	— 7'11
'40	— 1'38	103'50	— 3'38	'60	— 5'30	'70	— 7'15
'45	— 1'43	'55	— 3'43	'65	— 5'35	'75	— 7'20
101'50	— 1'48	'60	— 3'47	'70	— 5'39	'80	— 7'24
'55	— 1'53	'65	— 3'52	'75	— 5'44	'85	— 7'28
'60	— 1'57	'70	— 3'57	'80	— 5'48	'90	— 7'32
'65	— 1'62	'75	— 3'61	'85	— 5'53	'95	— 7'37
'70	— 1'67	'80	— 3'66	'90	— 5'57	108'00	— 7'41
'75	— 1'72	'85	— 3'71	'95	— 5'62	'05	— 7'45
'80	— 1'77	'90	— 3'75	106'00	— 5'66	'10	— 7'49
'85	— 1'82	'95	— 3'80	'05	— 5'71	'15	— 7'54
'90	— 1'87	104'00	— 3'85	'10	— 5'75	'20	— 7'58
'95	— 1'91	'05	— 3'90	'15	— 5'80	'25	— 7'62
102'00	— 1'96	'10	— 3'94	'20	— 5'84	'30	— 7'66
'05	— 2'01	'15	— 3'99	'25	— 5'88	'35	— 7'71
'10	— 2'06	'20	— 4'03	'30	— 5'93	'40	— 7'75
'15	— 2'10	'25	— 4'08	'35	— 5'98	'45	— 7'79
'20	— 2'15	'30	— 4'12	'40	— 6'02	108'50	— 7'83
'25	— 2'20	'35	— 4'17	'45	— 6'06	'55	— 7'88
'30	— 2'25	'40	— 4'21	106'50	— 6'10	'60	— 7'92
'35	— 2'30	'45	— 4'26	'55	— 6'15	'65	— 7'96
'40	— 2'34	104'50	— 4'31	'60	— 6'19	'70	— 8'00
'45	— 2'39	'55	— 4'36	'65	— 6'24	'75	— 8'05
102'50	— 2'44	'60	— 4'40	'70	— 6'28	'80	— 8'09
'55	— 2'49	'65	— 4'45	'75	— 6'33	'85	— 8'13
'60	— 2'53	'70	— 4'49	'80	— 6'37	'90	— 8'17
'65	— 2'58	'75	— 4'54	'85	— 6'41	'95	— 8'22
'70	— 2'63	'80	— 4'58	'90	— 6'45	109'00	— 8'26
'75	— 2'68	'85	— 4'63	'95	— 6'50	'05	— 8'30
'80	— 2'72	'90	— 4'67	107'00	— 6'54	'10	— 8'34
'85	— 2'78	'95	— 4'72	'05	— 6'59	'15	— 8'38

+ Signifies *Fast*.
 — " *Slow*.

TABLE N.—*Continued.*

SHOWING THE PER CENTAGE OF ERRORS IN METERS WHOSE REGISTRATION DIFFERS FROM THE INDICATIONS OF TEST GAS HOLDERS.

Meter Registering 100 Feet.—Continued.

Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.	Reading of Scale of Gas Holder	Amount of Error.
Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.	Feet.	Per Cent.
'20	— 8'42	'75	— 8'89	60	— 9'59	'70	— 10'47
'25	— 8'47	'80	— 8'93	70	— 9'67	'80	— 10'55
'30	— 8'51	'85	— 8'97	80	— 9'75	'90	— 10'63
'35	— 8'55	'90	— 9'01	90	— 9'83	112'00	— 10'71
'40	— 8'59	'95	— 9'05	100	— 9'91	'10	— 10'79
'45	— 8'64	110'00	— 9'09	10	— 9'99	'20	— 10'87
109'50	— 8'68	'10	— 9'18	20	— 10'07	'30	— 10'95
'55	— 8'72	'20	— 9'26	30	— 10'15	'40	— 11'03
'60	— 8'76	'30	— 9'34	40	— 10'23	'50	— 11'11
'65	— 8'80	'40	— 9'42	50	— 10'31		
'70	— 8'84	'50	— 9'51	60	— 10'39		

+ Signifies *Fast*.

— " *Slow*.

APPENDIX O.

DATA AS TO CALORIFIC POWERS, ANALYSES AND
ILLUMINATING POWERS OF VARIOUS GASES.

Note.—The following figures are collated from tests and records by Dr. Bunte, Dr. Harold Colman, F. G. Dexter, R. Forbes Carpenter, Thos. Fairley, Herbert A. Humphrey, T. Holgate, F. D. Marshall, T. O. Paterson, J. G. Taplay and the writer.

I.—COMPARATIVE TABLE OF CALORIFIC POWERS.

	*Per Cubic Foot Gross	
	B. T. U.	Calories.
<i>Producer Gas.</i>		
Siemens.....	134.5	34.0
Wilson.....	140.0	35.0
Dowson (from anthracite).....	155-160	39.0
Lencauchez (from anthracite).....	207.5	52.0
“ (fuel not specified).....	135-166	34-42
Mond.....	154.6	39
<i>Blast Furnace Gas.</i>		
Coke fed.....	100-110	25-28
Coal fed and washed.....	130-140	33-35
<i>Water Gas.</i>		
Uncarburetted, Lowe process.....	276-293	69-73.5
“ Dellwick and Strache.....	about 280	70
Carburetted, 22c. American.....	749.9	187.5
“ 21.7c. English.....	618.6	155
“ 22.7c. English.....	677.1	167
<i>Coal Gas.</i>		
16 to 22 Candle.....	650-750	162.5-188
London 16.4 Candle.....	648.8	162.2
<i>Coke Oven Gas.</i>		
Semet Solvay (average of ovens).....	511.2	128
Otto Hoffman, Everett, Boston, U.S.A. (average of ovens).....	567.0	142
“ Rich ” gas (22.1 candle).....	749.7	187.5
<i>Natural Gas.</i>		
Pittsburg (U.S.A.).....	892.4	223.1

**Note.*—To convert to net or “ lower ” heating power deduct about 10 per cent.

2.—COMPARATIVE TABLE OF ANALYSES IN PERCENTAGES AND SP. GR.

	Siemens.	Dowson.	Mond.	Lowe Water Gas uncarburetted.	Dellwik uncarburetted.	Humphreys & Glasgow's Water Gas.	Coal Gas.	Coke Oven Gas.
CO ₂	2 to 7	6 to 7	16.0	3 to 7	about 4.0	0.2 to 2.2	1 to 2	about 5.0
CO	23 to 30	23 to 27	11.0	40.0	about 40.0	23 to 28	3 to 9	about 1.0
CH ₄	trace	0.5 to 2.0	2.0	trace	trace	17 to 21	32 to 40	about 19.0
H	2 to 6	17 to 18	29.0	50.0	about 52.0	31 to 38	40 to 54	about 22.5
C _n H _m						13 to 16	3 to 6	
N	50 to 65	47 to 52	42.0	3 to	about 3.0	2.5 to 5	1 to 5	about 44.0
Specific Gravity (air=1)	about 1.0	0.83	0.788	0.51	about 0.5 carburetted 0.6	0.58 to 0.6	0.4 to 0.5	

3.—EXAMPLE FOR CALCULATION OF CALORIFIC BALANCE OF COAL.

Data : 1 ton of coal, calorific power 3,500 calories per lb., yields

11,205 cu. ft. of gas, " 141 " " cu. ft.
 1,540 lbs. of coke, " 3,150 " " lb.
 163 " " tar, " 3,900 " " "

Therefore : calorific value of 1 ton of coal = 7,840,000 cal.
 " " of gas = 1,568,700 cal.
 " " of coke = 4,851,000 "
 " " of tar = 635,700 "
 loss = 784,600 "
 loss per cent. = about 10%.

4.—THE CALORIFIC POWER OF CARBON.

Heat of combustion of carbon to CO₂ =

8.080 kilo-calories (1 gramme fuel, 1 kilo water, 1° C.)
 or 8080 gramme-calories (1 gramme fuel, 1 gramme water, 1° C.)
 or 14,544 B. T. U's (1 lb. fuel, 1 lb. water, 1° F.)
 or 3665 kilo-calories, per lb. (1 lb. fuel, 1 kilo water, 1° C.)

The above are based upon the classical "8.080" of Favre & Silbermann, and the heat value of a carbonaceous fuel can be found if the percentage of pure carbon is known; or it can be ascertained by Calorimeter as in Chapter VI.

5.—TABLE OF HEAT EVOLVED, &C., BY THE COMBUSTION OF VARIOUS GASES.

Name.	Molecular Formula.	Vol. air required for each vol.	Vol. oxygen required for each vol.	Vols. of Products.		B. T. U's gross per cubic foot at 60° Fahrenheit and 30 inches pressure.
				CO ₂	H ₂ O	
Hydrogen	H ₂	2.38	0.5	—	1.0	326.2
Carbon Monoxide	CO	2.38	0.5	1.0	—	323.5
Methane	CH ₄	9.52	2.0	1.0	2.0	1009.0
Ethane	C ₂ H ₆	16.66	3.5	2.0	3.0	1764.4
Propane	C ₃ H ₈	23.8	5.0	3.0	4.0	2521.0
Butane	C ₄ H ₁₀	30.94	6.5	4.0	5.0	3274.0
Pentane	C ₅ H ₁₂	38.08	8.0	5.0	6.0	
Hexane	C ₆ H ₁₄	45.22	9.5	6.0	7.0	
Heptane	C ₇ H ₁₆	52.36	11.0	7.0	8.0	
Paraffins (C _n H _{2n+2})						
Ethylene	C ₂ H ₄	14.28	3.0	2.0	2.0	1588.0
Propylene	C ₃ H ₆	21.42	4.5	3.0	3.0	2347.2
Butylene	C ₄ H ₈	28.56	6.0	4.0	4.0	3099.2
Amylene	C ₅ H ₁₀	35.70	7.5	5.0	5.0	
Hexylene	C ₆ H ₁₂	42.84	9.0	6.0	6.0	
Olefines (C _n H _{2n})						
Acetylene	C ₂ H ₂	11.90	2.5	2.0	1.0	1476.7
Allylene	C ₃ H ₄	19.04	4.0	3.0	2.0	2255.0
(C _n H _{2n-2})						
Benzene	C ₆ H ₆	35.70	7.5	6.0	3.0	3807.4
Toluene	C ₇ H ₈	42.84	9.0	7.0	4.0	
Xylene	C ₈ H ₁₀	49.98	10.5	8.0	5.0	
(C _n H _{2n-6})						
Naphthalene	C ₁₀ H ₈	57.12	12.0	9.0	6.0	

6.—TABLE SHOWING GROSS CALORIES, PER CANDLE, OF GASES
OF VARYING ILLUMINATING POWERS.

NOTE.—The columns marked A, B, C, D and E, are results obtained by different experimentalists.

CANDLE POWER.	Gross Calories Per Candle.				
English Candles.	A.	B.	C.	D.	E.
11.0	12.1				
12.0	11.6		12.5		
13.0	11.1		11.5	11.0	
14.0	10.8			10.6	
15.0	10.4			10.0	10.0
16.0	10.1	9.5	10.1	9.6	9.5
17.0	9.9	8.9		9.3	10.0
18.0	9.8	8.5	9.2	9.0	
19.0		8.0		8.7	
20.0				8.7	

It will be seen that whilst the tendency to an increased heat duty per candle, as the illuminating power decreases, is general, there are discrepancies between different experimentalist's results for the same candle power.

The following tables (8 and 9), and the data below (7), giving the comparative heating and illuminating values of carburine (light petroleum naphtha) and benzol will show how such divergencies are obtained, and emphasise the necessity of tests being carried out as recommended in Chapter IV.

7.—COMPARISON BETWEEN CARBURINE AND BENZOL AS TO
ENRICHMENT VALUE FOR LIGHTING AND HEATING.

Enricher.	Galls. used to enrich 10,000 cu. ft. 1 candle.	Cu. ft. of vapour.	Enrichment value in candles, for 1 per cent. added.	Heating value, 1 gallon, in B. T. U.	Proportional heat enrich- ment for quantities taken, to raise 10,000 cu. ft. 1 candle.
Carburine.	2.4	72	1.41	150909.1	36.21 B. T. U. per cu. ft.
Benzol.	0.89	35.6	2.86	159821.6	14.22 " "

Therefore, although benzol has a light-enrichment value of 2.7 times that of carburine, its heat-enrichment value (for the same increase in candle power, viz., 1 candle) is only 0.4 of that of carburine.

8.—THE INFLUENCE OF CARBONIC ACID ON THE COMBUSTION
OF COAL AND CARBURETTED WATER GAS. (DEXTER.)

COAL GAS.
Calorific Values.

Percentage of Carbonic Acid Present.	18.4 Candle Power.	18.0 Candle Power.	17.5 Candle Power.	15.6 Candle Power.
Nil.	167 } Loss	166 } Loss	166 } Loss	164 } Loss
2.5	162 } 11	161 } 14	159 } 16	155 } 21
5.0	157 } Per	155 } Per	152 } Per	146 } Per
7.5	152 } Cent	149 } Cent.	146 } Cent.	139 } Cent.
10.0	148 }	143 }	139 }	130 }

CARBURETTED WATER GAS.
Calorific Values.

Percentage of Carbonic Acid Present.	21.6 Candle Power.	20.8 Candle Power.	18.0 Candle Power.	11.7 Candle Power.
Nil.	148 } Loss	146 } Loss	144 } Loss	124 } Loss
2.5	144 } 13	141 } 14	138 } 19	120 } 14
5.0	139 } Per	135 } Per	131 } Per	115 } Per
7.5	134 } Cent.	130 } Cent.	124 } Cent.	111 } Cent.
10.0	130 }	125 }	117 }	107 }

8.—THE INFLUENCE OF CARBONIC ACID ON THE COMBUSTION OF COAL AND CARBURETTED WATER GAS.

Continued. (DEXTER.)

COAL GAS.

Illuminating Values.

Percentage of Carbonic Acid Present.	18.4 Candle Power.	18.0 Candle Power.	17.5 Candle Power.	15.6 Candle Power.
Nil.	18.4	18.0	17.5	15.6
2.5	16.9	16.5	16.1	13.9
5.0	15.4	15.0	14.6	12.2
7.5	13.9	13.5	13.1	10.6
10.0	12.4	12.0	11.7	8.9

CARBURETTED WATER GAS.

Illuminating Values.

Percentage of Carbonic Acid Present.	21.6 Candle Power.	18 Candle Power.	11.7 Candle Power.
Nil.	21.6	18.0	11.7
2.5	19.7	15.7	9.7
5.0	17.8	13.4	7.8
7.5	15.9	11.2	5.8
10.0	14.0	8.9	3.8

9.—TABLE SHOWING THE COMPARATIVE EFFECT ON ILLUMINATING AND HEATING POWER OF THE DILUTION OF COAL GAS WITH UNCARBURETTED WATER GAS.

Percentage of Coal Gas.	Illum. Power Eng. Candles	Heating Power Gross Calories per cu. ft.	Calories per Candle.
100	19.29	169.	8.7
90	18.45	162	8.8
80	16.67	154	9.2
70	14.26	146.5	10.3
60	11.89	136	11.4
50	9.88	129	13.1
40	5.08	117.5	23.1
30	under 1	109.3	
20	" "	101.2	
10	" "	93.1	

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